INTERNAL EXHAUST GAS RECIRCULATION AMOUNT ESTIMATION SYSTEM OF INTERNAL COMBUSTION ENGINES

TECHNICAL FIELD

5   The present invention relates to an internal exhaust gas recirculation (internal EGR) amount estimation system for internal combustion engines, and specifically to the improvement of estimation of internal EGR relating to a valve overlap period during which both of intake and exhaust

10   valves are open together.

BACKGROUND ART

As is generally known, in order to attain both a reduction in the amount of nitrogen oxides (NOx) produced by an internal combustion engine, based on an increase in inert

15   gases contributing to a reduced combustion temperature, and a reduction in pumping loss contributing to a reduced fuel consumption, a spark-ignition internal combustion engine often uses a variable valve operating mechanism so as to actively increase a valve overlap that the open periods of

20   intake and exhaust valves are overlapped, and consequently to increase the amount of internal EGR. In such a case, it is more desirable to simultaneously optimize or compensate for an ignition timing, a fuel-injection amount, a valve open timing and a valve closure timing of at least one of

25   intake and exhaust valves, and the like, responsively to a change in internal EGR. One such internal EGR estimation method has been disclosed in Japanese Patent Provisional Publication No. 2001-221105 (hereinafter is referred to as "JP2001-221105"). According to the internal EGR estimation

30   method of JP2001-221105, a basic value of internal EGR, corresponding to the amount of burned gas remaining in the engine cylinder under a non-overlapped condition of the open periods of intake and exhaust valves, is calculated based on

engine operating conditions such as engine load, engine speed, an air/fuel mixture ratio (A/F), an EGR ratio of the amount of exhaust gas recirculated to the total gas amount per cylinder, and an intake-manifold pressure. During the

5   valve overlap, the estimate of internal EGR is increasingly compensated for by adding a valve-overlap correction value, which is based on a valve overlap period, a phase of a central crank angle between the beginning-of-valve-overlap crank angle and the end-of-valve-overlap crank angle, and

10 intake-manifold pressure, to the basic value of internal EGR calculated. However, in particular in a transient engine operating state that at least one of the engine load, engine speed, air/fuel mixture ratio, and intake-manifold pressure remarkably varies, it is difficult to univocally exactly

15 estimate the amount of internal EGR from the valve overlap period. Thus, it is desirable to more precisely estimate the amount of internal EGR depending on variations in engine operating conditions.

Additionally, under particular engine operating

20 conditions, such as just after starting with a cold engine, just after deceleration fuel-cutoff operating mode, or at high-speed high-load operation during which engine coolant temperature is very high, a valve clearance itself tends to remarkably change owing to thermal expansion of the engine

25 valve and shaft in the valve operating mechanism, arising from temperature changes in the valve and the cylinder head and cylinder block. This causes a deviation of the actual valve overlap period from a desired valve overlap, in other words, a deviation of the actual internal EGR amount from a

30 desired internal EGR amount computed based on the engine operating conditions. Such a deviation lowers the control accuracy of the electronic ignition timing control system and/or the electronic fuel injection control system, and

thereby results in the deteriorated vehicle drivability, increased fuel consumption, and lowered exhaust-emission performance.

SUMMARY OF THE INVENTION

5   Accordingly, it is an object of the invention to provide an internal EGR amount estimation system for an internal combustion engine, enabling very precise estimation of the amount of internal EGR varying owing to variations in engine operating conditions.

10   It is another object of the invention to provide an internal EGR amount estimation system for an internal combustion engine, capable of more precisely estimating the amount of internal EGR, taking into account of a change in valve clearance, occurring owing to thermal expansion of an

15 engine valve and a shaft in a valve operating mechanism and/or owing to moving-parts wear or motion-transmitting valve-train component parts wear such as cam and shim wear.

In order to accomplish the aforementioned and other objects of the present invention, an internal exhaust gas

20 recirculation amount estimation system of an internal combustion engine comprises an exhaust valve closure timing in-cylinder temperature calculation section that calculates an in-cylinder temperature at an exhaust valve closure timing, an exhaust valve closure timing in-cylinder pressure

25 calculation section that calculates an in-cylinder pressure at the exhaust valve closure timing, a gas constant calculation section that calculates a gas constant corresponding to a change in a composition of exhaust gas, based on an air-fuel mixture ratio, an exhaust valve closure

30 timing in-cylinder residual gas amount calculation section that calculates an in-cylinder residual gas amount at the exhaust valve closure timing, based on at least the in-cylinder temperature, the in-cylinder pressure, and the gas

constant, an valve overlap period blow-back gas amount
calculation section that calculates a valve overlap period
blow-back gas amount defined as a quantity of gas flow from
one of intake and exhaust ports via a combustion chamber to
5 the other port during a valve overlap period during which
both of intake and exhaust valves are open together, the gas
flow being created by a pressure difference between the
intake and exhaust ports, and an internal EGR amount
calculation section that calculates an internal exhaust gas
10 recirculation amount based on the exhaust valve closure
timing in-cylinder residual gas amount and the valve overlap
period blow-back gas amount.

According to another aspect of the invention, an
internal exhaust gas recirculation amount estimation system
15 of an internal combustion engine comprises exhaust valve
closure timing in-cylinder temperature calculation means for
calculating an in-cylinder temperature at an exhaust valve
closure timing, exhaust valve closure timing in-cylinder
pressure calculation means for calculating an in-cylinder
20 pressure at the exhaust valve closure timing, gas constant
calculation means for calculating a gas constant
corresponding to a change in a composition of exhaust gas,
based on an air-fuel mixture ratio, exhaust valve closure
timing in-cylinder residual gas amount calculation means for
25 calculating an in-cylinder residual gas amount at the
exhaust valve closure timing, based on at least the in-
cylinder temperature, the in-cylinder pressure, and the gas
constant, valve overlap period blow-back gas amount
calculation means for calculating a valve overlap period
30 blow-back gas amount defined as a quantity of gas flow from
one of intake and exhaust ports via a combustion chamber to
the other port during a valve overlap period during which
both of intake and exhaust valves are open together, the gas

flow being created by a pressure difference between the
intake and exhaust ports, and internal EGR amount
calculation means for calculating an internal exhaust gas
recirculation amount based on the exhaust valve closure
5   timing in-cylinder residual gas amount and the valve overlap
period blow-back gas amount.

According to a further aspect of the invention, a
method of estimating an internal exhaust gas recirculation
amount of an internal combustion engine enabling the
10   internal exhaust gas recirculation amount to be varied by
changing a valve overlap, the method comprises calculating
an in-cylinder temperature at an exhaust valve closure
timing based on an exhaust temperature, calculating an in-
cylinder pressure at the exhaust valve closure timing based
15   on an exhaust pressure, calculating a gas constant
corresponding to a change in a composition of exhaust gas,
based on an air-fuel mixture ratio, calculating an in-
cylinder residual gas amount at the exhaust valve closure
timing, based on at least the in-cylinder temperature, the
20   in-cylinder pressure, and the gas constant, detecting an
engine speed, calculating a valve overlap period integrated
effective area for an opening area of the intake valve and
an opening area of the exhaust valve during the valve
overlap period, determining the presence or absence of a
25   supercharging phenomenon regarding the gas flow between the
intake and exhaust ports via the combustion chamber during
the valve overlap period, the gas flow being created by the
pressure difference between the intake and exhaust ports,
and the presence or absence of a choking phenomenon
30   regarding the gas flow between the intake and exhaust ports
via the combustion chamber during the valve overlap period,
calculating a valve overlap period blow-back gas amount,
which is defined as a quantity of gas flow from one of

intake and exhaust ports via a combustion chamber to the other port during a valve overlap period during which both of intake and exhaust valves are open together, and is based on the engine speed, the valve overlap period integrated

5 effective area, and the supercharging-and-choking phenomena decision result regarding the presence or absence of the supercharging phenomenon, and the presence or absence of the choking phenomenon, and calculating the internal exhaust gas recirculation amount by adding the valve overlap period

10 blow-back gas amount to the exhaust valve closure timing in-cylinder residual gas amount.

The other objects and features of this invention will become understood from the following description with reference to the accompanying drawings.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a system diagram illustrating one embodiment of an internal EGR estimation system.

Fig. 2 is a block diagram relating to an internal EGR ratio MRESFR calculation section.

20 Fig. 3 is a block diagram relating to an internal EGR amount MRES calculation section.

Fig. 4 is a block diagram relating to an exhaust valve closure timing in-cylinder residual gas amount MRESCYL calculation section.

25 Fig. 5 is a block diagram relating to a valve overlap period blow-back gas amount MRESOL calculation section.

Fig. 6 is a block diagram relating to an exhaust-gas ratio-of-specific-heat SHEATR calculation section.

Fig. 7 is a block diagram relating to a supercharging-

30 and-choking phenomena determination section.

Fig. 8 is a flow chart showing an internal EGR ratio MRESFR (unit: %) calculation routine.

Fig. 9 is a flow chart showing an internal EGR amount MRES (unit: kg) calculation routine.

Fig. 10 is a flow chart showing an exhaust valve closure timing in-cylinder residual gas amount MRESCYL (unit: kg) calculation routine.

Fig. 11 is a flow chart showing a valve overlap period blow-back gas amount MRESOL (unit: kg) calculation routine.

Fig. 12 is a flow chart showing a supercharging/choking phenomena determination routine.

Fig. 13 is a flow chart showing a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) calculation routine executed in an unsupercharged and unchoked state.

Fig. 14 is a flow chart showing a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) calculation routine executed in an unsupercharged and choked state.

Fig. 15 is a flow chart showing a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) calculation routine executed in an supercharged and unchoked state.

Fig. 16 is a flow chart showing a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) calculation routine executed in an supercharged and choked state.

Fig. 17 is a preprogrammed lookup table showing the relationship between a variation VTEOFS of exhaust valve closure timing EVC and an exhaust valve closure timing in-cylinder volumetric capacity VEVC (unit: m^3).

Fig. 18 is a preprogrammed lookup table showing the relationship between a target combustion equivalent ratio TFBYA and an exhaust-gas gas constant REX (unit: J/kgK).

Fig. 19 is a preprogrammed lookup table showing the relationship between a variation VTCOL of valve overlap and a valve overlap period integrated effective area ASUMOL (unit: m^3).

Fig. 20 is an explanatory drawing showing valve overlap period integrated effective area ASUMOL.

Fig. 21 is a preprogrammed lookup table (a predetermined characteristic map) showing the relationship among target combustion equivalent ratio TFBYA, an exhaust valve closure timing in-cylinder temperature TEVC (unit: K), and an exhaust-gas ratio-of-specific-heat SHEATR.

Fig. 22 is a preprogrammed lookup table (a predetermined characteristic map) showing the relationship between target combustion equivalent ratio TFBYA and an air-fuel mixture ratio-of-specific-heat MIXAIRSHR.

Fig. 23 is a block diagram relating to an exhaust valve closure timing in-cylinder volumetric capacity VEVC calculation section.

Fig. 24 is a block diagram relating to an EVC variation VTEOFS calculation section.

Fig. 25 is a block diagram relating to a valve clearance (exhaust valve clearance VCLE and intake valve clearance VCLI) calculation section.

Fig. 26 is a block diagram relating to a valve-timing-correction learned value (EVC-correction learned value VTHOSE and IVO-correction learned value VTHOSI) calculation section.

Fig. 27 is a block diagram relating to a valve overlap period integrated effective area ASUMOL (unit: m^3) calculation section.

Fig. 28 is a block diagram relating to an IVO variation VTIOFS calculation section.

Fig. 29 is a flow chart showing an exhaust valve closure timing in-cylinder volumetric capacity VEVC (unit: m^3) calculation routine.

Fig. 30 is a flow chart showing an EVC variation VTEOFS calculation routine.

Fig. 31 is a flow chart showing a valve clearance (exhaust valve clearance VCLE and intake valve clearance VCLI) calculation routine.

Fig. 32 is a flow chart showing a valve-timing-correction learned value (EVC-correction learned value VTHOSE and IVO-correction learned value VTHOSI) calculation routine.

Fig. 33 is a flow chart showing an actual valve timing (actual exhaust valve closure timing VCLTRE and actual intake valve open timing VCLTRI) calculation enabling flag setting/resetting routine.

Fig. 34 is a flow chart showing a valve overlap period integrated effective area ASUMOL (unit: m^3) calculation routine.

Fig. 35 is a flow chart showing an IVO variation VTIOFS calculation routine.

Fig. 36A is a preprogrammed lookup table showing the relationship between an exhaust valve clearance VCLE and an exhaust-valve temperature dependent EVC-variation correction value VTCLE.

Fig. 36B is a preprogrammed lookup table showing the relationship between an intake valve clearance VCLI and an intake-valve temperature dependent IVO-variation correction value VTCLI.

Fig. 37A is a preprogrammed lookup table showing the relationship between a fuel injection amount and an exhaust-valve temperature VTMPE.

Fig. 37B is a preprogrammed lookup table showing the relationship between a fuel injection amount and an intake-valve temperature VTMPI.

Fig. 38 is a characteristic map showing the
5 relationship among EVC variation VTEOFS, IVO variation VTIOFS, and valve overlap period integrated effective area ASUMOL.

Fig. 39 is an explanatory drawing showing a direction (clockwise direction) of a positive variation in EVC.

10 Fig. 40 is an explanatory drawing showing a direction (anticlockwise direction) of a negative variation in IVO.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, particularly to Fig. 1, the internal exhaust gas recirculation (EGR) amount
15 estimation system is exemplified in a double-overhead-camshaft internal combustion engine 1 employing a variable valve timing device enabling a valve characteristic, such as an engine valve open timing and an engine valve closure timing, to be varied. A combustion chamber 3 is defined
20 between the inner wall of the cylinder head and a reciprocating piston 2, fitted to each engine cylinder. An intake valve 5, which opens and closes an intake port 5p of combustion chamber 3, and an exhaust valve 6, which opens and closes an exhaust port 6p of combustion chamber 3, are
25 provided in such a manner as to surround a spark plug 4 mounted on the cylinder head. An exhaust valve characteristic (containing an exhaust valve open timing EVO and an exhaust valve closure timing EVC) is variably controlled by changing a phase of an exhaust-valve cam
30 relative to its camshaft by means of an electromagnetic exhaust-valve solenoid (a variable exhaust-valve operating solenoid) 23 included in a variable exhaust-valve timing mechanism. On the other hand, an intake valve

characteristic (containing an intake valve open timing IVO and an intake valve closure timing IVC) is variably controlled by changing a phase of an intake-valve cam relative to its camshaft by means of an electromagnetic intake-valve solenoid (a variable intake-valve operating solenoid) 22 included in a variable intake-valve timing mechanism. An electronically-controlled throttle valve 19 is provided in an intake-air passage 7, so as to adjust a quantity of intake air (fresh air) flowing through intake-air passage 7 toward combustion chamber 3. Fuel spray is delivered via fuel injectors 20 to the individual cylinders. As shown in Fig. 1, fuel injector 20 is usually installed on the intake-air passage for each individual engine cylinder. On in-cylinder direct injection engines, the fuel injection nozzle of each injector is directly exposed to the individual combustion chamber for direct fuel injection. When spark plug firing is initiated, the air-fuel mixture in combustion chamber 3 is ignited and combusted. Then, the burned gas is exhausted into an exhaust passage 8. The operations of electronically-controlled throttle valve 19, injectors 20, spark plugs 4 each containing a power-transistor built-in ignition coil 21, variable intake-valve operating solenoid 22 and variable exhaust-valve operating solenoid 23 are controlled by means of an electronic engine control unit (ECU) 30. As seen from the system diagram shown in Fig. 1, ECU 30 generally comprises a microcomputer. ECU 30 includes an input/output interface (I/O), memories (RAM, ROM), and a microprocessor or a central processing unit (CPU). The input/output interface (I/O) of ECU 30 receives input information from various engine/vehicle sensors, namely a crank angle sensor (or a crankshaft position sensor) 14, an intake-valve cam angle sensor 16, an exhaust-valve cam angle sensor 17, an airflow meter 9, an

intake pressure sensor 10, an exhaust pressure sensor 11, an exhaust gas temperature sensor 12, an oxygen sensor (O_2 sensor) 13, an engine temperature sensor 15, an accelerator opening sensor (or an accelerator position sensor) 18, and a

5   knock sensor 25. Crank angle sensor 14 is provided to generate a crank angle signal in synchronism with rotation of the engine, and to inform the ECU of the relative position of the engine crankshaft, as well as the engine speed. Intake-valve cam angle sensor 16 is provided to

10   detect a cam angle of the camshaft of intake valve 5 and thus to detect the operating condition of variable intake-valve operating solenoid 22, whereas exhaust-valve cam angle sensor 17 is provided to detect a cam angle of the camshaft of exhaust valve 6 and thus to detect the operating

15   condition of variable exhaust-valve operating solenoid 23. Airflow meter 9 is installed to measure the quantity of intake air (fresh air) flowing through intake-air passage 7 into the engine cylinder. Intake pressure sensor 10 is located downstream of electronically-controlled throttle

20   valve 19 to detect an intake pressure PIN. Exhaust pressure sensor 11 is usually threaded into an exhaust pipe defining therein an exhaust passage 8 to detect an exhaust pressure, which is used to estimate an in-cylinder pressure PEVC at exhaust valve closure timing EVC. Exhaust temperature

25   sensor 12 is usually threaded into the exhaust pipe defining exhaust passage 8 to detect an exhaust temperature, which is used to estimate an in-cylinder temperature TEVC at exhaust valve closure timing EVC. Oxygen sensor 13 is usually screwed into the exhaust pipe to monitor or detect the

30   percentage of oxygen contained within engine exhaust gases at all times when the engine is running. Engine temperature sensor 15 is located on the engine and usually screwed into one of the top coolant passages to detect an engine coolant

temperature Tw (an actual engine operating temperature of engine 1). Accelerator opening sensor 18 is generally positioned near the accelerator pedal to inform the ECU of an accelerator opening. Knock sensor 25 is attached to the

5   engine to supply the ECU with a knock sensor signal corresponding to the engine knock frequency. Note that, in the system of the shown embodiment, knock sensor 25 also serves to detect the frequency of oscillatory seating motion of each of intake valve 5 and exhaust valve 6 that creates

10   metallic sound. Within ECU 30, the central processing unit (CPU) allows the access by the I/O interface of input informational data signals from the previously-discussed engine/vehicle sensors 9-18 and 25. The CPU of ECU 30 is responsible for carrying the control program stored in

15   memories and is capable of performing necessary arithmetic and logic operations containing an electronic engine control achieved through electronically-controlled throttle valve 19 and injectors 20 involved in an electronic fuel injection system, spark plugs 4 involved in an electronic ignition

20   system, and variable valve operating solenoids 22 and 23 involved in the electronic variable valve timing control system. Computational results (arithmetic calculation results), that is, calculated output signals are relayed through the output interface circuitry of the ECU to output

25   stages, namely a throttle actuator of electronically-controlled throttle valve 19, fuel injectors 20, spark plugs 4, and variable valve operating solenoids 22 and 23.

The internal EGR amount estimation procedures executed by the system of the embodiment are hereinafter described in

30   detail in reference to the block diagrams shown in Figs. 2-7, the flow charts shown in Figs. 8-16, and the lookup tables shown in Figs. 17-22.

First of all, a way to calculate internal EGR ratio
MRESFR is hereunder explained by reference to the block
diagram of Fig. 2 and the internal EGR ratio MRESFR
(unit: %) calculation routine of Fig. 8.

5   As seen
from the block diagram of Fig. 2, an intake-air quantity per
cylinder calculation section calculates an intake-air
quantity per cylinder (a fresh-air quantity per cylinder)
MACYL, a target combustion equivalent ratio calculation

10   section calculates a target combustion equivalent ratio
TFBYA, an internal EGR amount calculation section calculates
an internal EGR amount per cylinder MRES (unit: kg), and
then the internal EGR ratio calculation section calculates
an internal EGR ratio MRESFR (unit: %) based on the

15   calculated values MACYL, TFBYA, and MRES. In more detail,
as shown in the flow chart of Fig. 8, at step S1, intake-air
quantity per cylinder MACYL is calculated or computed based
on an intake-air quantity measured by airflow meter 9. At
step S2, target combustion equivalent ratio TFBYA is

20   calculated and determined based on latest up-to-date
information regarding the engine speed detected based on a
signal from crank angle sensor 14, accelerator opening
detected based on a signal from accelerator opening sensor
18, and engine coolant temperature detected based on a

25   signal from engine temperature sensor 15. On the assumption
that a stoichiometric air/fuel mixture ratio is 14.7, target
combustion equivalent ratio TFBYA is derived based on a
desired air-fuel mixture ratio from the following expression
(1).

30   TFBYA = 14.7/(DESIRED AIR/FUEL MIXTURE RATIO) $\cdots\cdots$(1)
Thus, when the desired air/fuel (A/F) ratio is the
stoichiometric A/F ratio (= 14.7), target combustion

equivalent ratio TFBYA is calculated as "1" from the aforementioned expression (1).

Then, at step S3 of Fig. 8, internal EGR amount per cylinder MRES (unit: kg) is calculated in accordance with
5 the flow chart shown in Fig. 9. After a series of steps S1-S3, at step S4 internal EGR ratio MRESFR (unit: %) is calculated as a ratio of the amount of internal EGR per cylinder to the total gas amount per cylinder from the following expression (2).

10 $$MRESFR = MRES/\{MRES+MACYL\times(1+TFBYA/14.7)\} \cdots\cdots(2)$$

Second, a way to calculate internal EGR amount per cylinder MRES (relating to step S3 of Fig. 8) is hereunder explained by reference to the block diagram of Fig. 3 and the internal EGR amount per cylinder MRES (unit: kg)
15 calculation routine of Fig. 9.

As seen from the block diagram of Fig. 3, an exhaust valve closure timing in-cylinder residual gas amount calculation section calculates an exhaust valve closure timing in-cylinder residual gas amount (hereinafter is
20 referred to as "EVC in-cylinder residual gas amount") MRESCYL (unit: kg), a valve overlap period blow-back gas amount calculation section calculates a valve overlap period blow-back gas amount (hereinafter is referred to as "O/L period blow-back gas amount") MRESOL (unit: kg), and then
25 the internal EGR amount per cylinder MRES (unit: kg) calculation section calculates internal EGR amount per cylinder MRES (unit: kg) based on the calculated values MRESCYL and MRESOL. In more detail, as shown in the flow chart of Fig. 9, at step S5, EVC in-cylinder residual gas
30 amount MRESCYL (unit: kg), corresponding to the amount of burned gas remaining in the engine cylinder at the exhaust valve closure timing EVC, is calculated in accordance with the flow chart shown in Fig. 10. At step S6, O/L period

blow-back gas amount MRESOL (unit: kg) is calculated in
accordance with the flow chart shown in Fig. 11. O/L period
blow-back gas amount MRESOL means a quantity of gas flow
from one of intake and exhaust ports 5p and 6p via

5   combustion chamber 3 to the other port during a valve
overlap period during which both of the intake and exhaust
valves are open together. When a gas flows from exhaust
port 6p toward combustion chamber 3 and then blows from
combustion chamber 3 back to intake port 5p during a valve

10   overlap period, the value of O/L period blow-back gas amount
MRESOL is defined as a positive value. On the contrary,
when a gas flows from intake port 5p toward combustion
chamber 3 and then blows from combustion chamber 3 through
exhaust port 6p during a valve overlap period, the value of

15   O/L period blow-back gas amount MRESOL is defined as a
negative value. That is, O/L period blow-back gas amount
MRESOL corresponds to the quantity of gas flow between
intake and exhaust ports 5p and 6p via combustion chamber 3
during a valve overlap period, the gas flow being created by

20   the pressure difference between the intake and exhaust ports
5p and 6p (exactly, the pressure difference between the
intake-port pressure and the in-cylinder pressure and the
pressure difference between the in-cylinder pressure and the
exhaust-port pressure). After a series of steps S5-S6, at

25   step S7 internal EGR amount per cylinder MRES (unit: kg) is
arithmetically calculated by adding O/L period blow-back gas
amount MRESOL to EVC in-cylinder residual gas amount MRESCYL,
from the following physical expression (3).

$$MRES = MRESCYL + MRESOL \quad \cdots\cdots(3)$$

30   Third, a way to calculate EVC in-cylinder residual gas
amount MRESCYL (relating to step S5 of Fig. 9) is hereunder
explained by reference to the block diagram of Fig. 4 and

the EVC in-cylinder residual gas amount MRESCYL (unit: kg) calculation routine of Fig. 10.

As seen from the block diagram of Fig. 4, the target combustion equivalent ratio calculation section calculates
5   target combustion equivalent ratio TFBYA of exhaust gases, and thereafter an exhaust-gas gas constant calculation section calculates an exhaust-gas gas constant REX (unit: J/kgK) based on target combustion equivalent ratio TFBYA, that is, a gas constant REX corresponding to a change in a
10 composition of exhaust gas, based on an air/fuel mixture ratio. An exhaust valve closure timing in-cylinder volumetric capacity calculation section calculates an exhaust valve closure timing in-cylinder volumetric capacity (hereinafter is referred to as "EVC in-cylinder volumetric
15 capacity") VEVC (unit: m^3), an exhaust valve closure timing in-cylinder temperature calculation section calculates an exhaust valve closure timing in-cylinder temperature (hereinafter is referred to as "EVC in-cylinder temperature") TEVC, an exhaust valve closure timing in-
20 cylinder pressure calculation section calculates an exhaust valve closure timing in-cylinder pressure (hereinafter is referred to as "EVC in-cylinder pressure") PEVC. Then, the EVC in-cylinder residual gas amount calculation section calculates EVC in-cylinder residual gas amount MRESCYL
25 (unit: kg) based on the calculated values VEVC, REX, TEVC and PEVC. In more detail, as shown in the flow chart of Fig. 10, at step S8, EVC in-cylinder volumetric capacity VEVC is calculated or retrieved based on a variation VTEOFS of exhaust valve closure timing EVC from a predetermined
30 VTEOFS-VEVC lookup table of Fig. 17 showing how an EVC in-cylinder volumetric capacity VEVC has to be varied relative to a variation VTEOFS of exhaust valve closure timing EVC. Details of calculation for EVC in-cylinder volumetric

capacity VEVC (relating to step S8 of Fig. 10) will be fully
described later by reference to the block diagram of Fig. 23
and the EVC in-cylinder volumetric capacity VEVC (unit: m^3)
calculation routine of Fig. 29. On internal combustion

5 engines employing a variable exhaust-valve timing mechanism,
the variation VTEOFS of exhaust valve closure timing EVC is
determined based on latest up-to-date information regarding
the cam angle of the camshaft of exhaust valve 6, detected
based on a signal from exhaust-valve cam angle sensor 17.

10 As seen from the lookup table of Fig. 17, EVC in-cylinder
volumetric capacity VEVC becomes a minimum nearby the piston
top dead center (TDC) position. A portion of the
characteristic curve of the right-hand side from the TDC
position indicates variations in EVC in-cylinder volumetric

15 capacity VEVC before the TDC position. In other words, as
can be appreciated from the lookup table of Fig. 17, EVC in-
cylinder volumetric capacity VEVC is geometrically
determined based on the position of the reciprocating piston
at the exhaust valve closure timing EVC. On internal

20 combustion engines also employing a variable compression
ratio mechanism (a variable piston stroke characteristic
mechanism) enabling a compression ratio ε of the engine to
be continuously varied by changing at least one of the top
dead center and the bottom dead center of the piston stroke

25 characteristic of reciprocating piston 2, EVC in-cylinder
volumetric capacity VEVC may be calculated or retrieved
based on a variation Δε of compression ratio ε controlled by
means of the variable compression ratio mechanism from a
predetermined ε-VEVC lookup table showing how an EVC in-

30 cylinder volumetric capacity VEVC has to be varied relative
to a compression-ratio variation Δε.

At step S9 of Fig. 10, exhaust-gas gas constant REX is
calculated or retrieved based on target combustion

equivalent ratio TFBYA from a predetermined TFBYA-REX lookup table of Fig. 18 showing how an exhaust-gas gas constant REX has to be varied relative to a target combustion equivalent ratio TFBYA. In the lookup table of Fig. 18, the broken

5   vertical line indicates a stoichiometric A/F ratio line that the desired A/F ratio is identical to the stoichiometric A/F ratio (= 14.7) and thus target combustion equivalent ratio TFBYA is "1". The right-hand side area indicates a rich A/F mixture area, whereas the left-hand side area indicates a

10   lean A/F mixture area. At step S10, EVC in-cylinder temperature TEVC is determined based on latest up-to-date information regarding the exhaust temperature, detected based on a signal from exhaust temperature sensor 12. Instead of using the sensor signal from exhaust temperature

15   sensor 12, EVC in-cylinder temperature TEVC may be estimated and determined, by way of retrieval for a predetermined or preprogrammed fuel-injection-amount versus EVC in-cylinder temperature TEVC lookup table showing the relationship between the fuel injection amount and EVC in-cylinder

20   temperature TEVC. This is because EVC in-cylinder temperature TEVC tends to vary owing to a quantity of heat created depending on a quantity of fuel injected and sprayed from injector 20. At step S11, EVC in-cylinder pressure PEVC is determined based on latest up-to-date information

25   regarding the exhaust pressure, detected based on a signal from exhaust pressure sensor 11. Instead of using the sensor signal from exhaust pressure sensor 11, EVC in-cylinder pressure PEVC may be estimated and determined, by way of retrieval for a predetermined or preprogrammed

30   mixture volumetric flow rate versus EVC in-cylinder pressure PEVC lookup table showing the relationship between the mixture volumetric flow rate and EVC in-cylinder pressure PEVC. This is because EVC in-cylinder pressure PEVC tends

to vary owing to a volume of air/fuel mixture and a fluid-flow resistance against exhaust gas flowing through the exhaust pipe of the exhaust system. After a series of steps S8-S11, at step S12 EVC in-cylinder residual gas amount

5 MRESCYL (unit: kg) is arithmetically calculated based on the calculated values VEVC, REX, TEVC, and PEVC, from the following physical expression (4).

$$MRESCYL = (PEVC \times VEVC)/(REX \times TEVC) \cdots (4)$$

Fourth, a way to calculate O/L period blow-back gas

10 amount MRESOL (relating to step S6 of Fig. 9) is hereunder explained by reference to the block diagram of Fig. 5 and the O/L period blow-back gas amount MRESOL (unit: kg) calculation routine of Fig. 11.

As seen from the block diagram of Fig. 5, the target

15 combustion equivalent ratio calculation section calculates target combustion equivalent ratio TFBYA of exhaust gases, and then the exhaust-gas gas constant calculation section calculates exhaust-gas gas constant REX (unit: J/kgK) based on target combustion equivalent ratio TFBYA. A valve

20 overlap period integrated effective area calculation section calculates a valve overlap period integrated effective area (hereinafter is referred to as "O/L period integrated effective area") ASUMOL (unit: m³) based on the variation VTEOFS of exhaust valve closure timing EVC and a variation

25 VTIOFS of intake valve open timing IVO, in accordance with the flow chart shown in Fig. 34, which will be fully described later. An engine speed calculation section calculates an engine speed NRPM (unit: rpm) based on a signal from crank angle sensor 14. The exhaust-gas gas

30 constant calculation section calculates exhaust-gas gas constant REX (unit: J/kgK) based on target combustion equivalent ratio TFBYA. An exhaust-gas ratio-of-specific-heat calculation section calculates an exhaust-gas ratio-of-

specific-heat SHEATR. The EVC in-cylinder temperature calculation section calculates EVC in-cylinder temperature TEVC. The EVC in-cylinder pressure calculation section calculates EVC in-cylinder pressure PEVC. An intake

5 pressure calculation section calculates an intake pressure PIN (unit: Pa) based on a signal from intake pressure sensor 10. A supercharging-and-choking phenomena determination section determines the presence (TBCRG=1) or absence (TBCRG=0) of the supercharging phenomenon regarding gas flow

10 between intake and exhaust ports 5p and 6p via combustion chamber 3 during a valve overlap period, the gas flow being created by the pressure difference between the pressure in the intake port and the pressure in the exhaust port, and the presence (CHOKE=1) or absence (CHOKE=0) of the choking

15 phenomenon regarding the gas flow between intake and exhaust ports 5p and 6p via combustion chamber 3 during the valve overlap period. The O/L period blow-back gas amount MRESOL calculation section calculates O/L period blow-back gas amount MRESOL (unit: kg) based on the calculated values

20 ASUMOL, NRPM, REX, SHEATR, TEVC, PEVC, PIN and the decision results, that is, the presence (TBCRG=1) or absence (TBCRG=0) of the supercharging phenomenon and the presence (CHOKE=1) or absence (CHOKE=0) of the choking phenomenon.

In more detail, as shown in the flow chart of Fig. 11,

25 at step S13, a variation VTCOL of a valve overlap O/L is arithmetically calculated based on (i) the variation VTIOFS of intake valve open timing IVO, which is determined based on latest up-to-date information regarding the cam angle (angular phase) of the camshaft of intake valve 5, detected

30 by intake-valve cam angle sensor 16 and (ii) the variation VTEOFS of exhaust valve closure timing EVC, which is determined based on latest up-to-date information regarding the cam angle (angular phase) of the camshaft of exhaust

valve 6, detected by exhaust-valve cam angle sensor 17, from
the following expression (5).

$$VTCOL = VTIOFS + VTEOFS \cdots\cdots(5)$$

Subsequently to step S13 of Fig. 11, at step S14 O/L

5   period integrated effective area ASUMOL (detailed later in
reference to the explanatory drawing of Fig. 20) is
calculated or retrieved based on the variation VTCOL of
valve overlap O/L from a predetermined VTCOL-ASUMOL lookup
table of Fig. 19 showing how an O/L period integrated

10 effective area ASUMOL has to be varied relative to a
variation VTCOL of valve overlap O/L. As clearly seen from
the characteristic curve of Fig. 19, O/L period integrated
effective area ASUMOL tends to increase in a non-linear
fashion, as the variation VTCOL of valve overlap O/L

15 increases.

Referring now to Fig. 20, there is shown the
relationship among the opening area of exhaust valve 6, the
opening area of intake valve 5, and O/L period integrated
effective area ASUMOL. The axis of abscissa of Fig. 20

20 indicates a crank angle, whereas the axis of ordinate of Fig.
20 indicates the opening area of intake valve 5 and the
opening area of exhaust valve 6. An effective engine-valve
opening area, which is obtained at a certain point of time
during the valve overlapping period, is defined and set as a

25 smaller one of the opening area of exhaust valve 6 and the
opening area of intake valve 5 at the certain time point by
way of a so-called select-LOW process. Therefore, O/L
period integrated effective area ASUMOL of the valve
overlapping period from the beginning-of-valve-overlap crank

30 angle to the end-of-valve-overlap crank angle is represented
and calculated as the integrated value (see the right-hand
diagonal shading area shown in Fig. 20) of the smaller valve
opening area per unit crank angle (or per unit time) from a

point of time corresponding to the beginning-of-valve-overlap crank angle to a point of time corresponding to the end-of-valve-overlap crank angle. By way of the aforementioned select-LOW process and the integral of an

5 effective opening area per unit crank angle (or unit time) from a time point (IVO) corresponding to the beginning-of-valve-overlap crank angle to a time point (EVC) corresponding to the end-of-valve-overlap crank angle, O/L period integrated effective area ASUMOL can be

10 arithmetically calculated. In other words, the valve overlap period, during which both of intake and exhaust valves 5 and 6 are open together, can be regarded as a pseudo variable orifice (a variable flow-constriction orifice) that serves to variably constrict the gas flow

15 between intake and exhaust ports 5p and 6p via combustion chamber 3. With the pseudo variable orifice having O/L period integrated effective area ASUMOL, the flow rate of gas passing through the pseudo variable orifice can be simply calculated or estimated.

20   Subsequently to step S14 of Fig. 11, at step S15 engine speed NRPM (unit: rpm) is calculated based on the sensor signal from crank angle sensor 14.

       At step S16, exhaust-gas ratio-of-specific-heat SHEATR is calculated or retrieved from a predetermined

25 characteristic map of Fig. 21 showing how an exhaust-gas ratio-of-specific-heat SHEATR has to be varied relative to a target combustion equivalent ratio TFBYA and an exhaust valve closure timing in-cylinder temperature TEVC (unit: K). A way to calculate exhaust-gas ratio-of-specific-heat SHEATR

30 is hereunder explained by reference to the block diagram of Fig. 6.

       As seen from the block diagram of Fig. 6, the target combustion equivalent ratio calculation section calculates

target combustion equivalent ratio TFBYA, and the exhaust
valve closure timing in-cylinder temperature calculation
section calculates exhaust valve closure timing in-cylinder
temperature TEVC (unit: K). Then, the exhaust-gas ratio-of-

5   specific-heat calculation section calculates exhaust-gas
ratio-of-specific-heat SHEATR based on the calculated values
TFBYA and TEVC. In the predetermined characteristic map
shown in Fig. 21, the axis of abscissa of Fig. 21 indicates
target combustion equivalent ratio TFBYA, whereas the axis

10 of ordinate of Fig. 21 indicates exhaust-gas ratio-of-
specific-heat SHEATR. In the characteristic map of Fig. 21,
the broken vertical line indicates a stoichiometric A/F
ratio line that the desired A/F ratio is identical to the
stoichiometric A/F ratio (= 14.7) and thus target combustion

15 equivalent ratio TFBYA is "1". In Fig. 21, the right-hand
side area indicates a rich A/F mixture area, whereas the
left-hand side area indicates a lean A/F mixture area. As
can be seen from the predetermined characteristic map of Fig.
21, exhaust-gas ratio-of-specific-heat SHEATR becomes a

20 smallest value when target combustion equivalent ratio TFBYA
is nearby the stoichiometric A/F ratio (= 14.7). Exhaust-
gas ratio-of-specific-heat SHEATR tends to increase, as
target combustion equivalent ratio TFBYA increases from "1"
to a larger value (a richer mixture). Additionally,

25 exhaust-gas ratio-of-specific-heat SHEATR tends to increase,
as target combustion equivalent ratio TFBYA decreases from
"1" to a smaller value (a leaner mixture). Furthermore,
exhaust-gas ratio-of-specific-heat SHEATR tends to reduce,
as EVC in-cylinder temperature TEVC (indicated by the arrow

30 directed downwards in Fig. 21) rises. Actually, exhaust-gas
ratio-of-specific-heat SHEATR is map-retrieved based on both
of target combustion equivalent ratio TFBYA calculated at
step S2 of Fig. 8 (see the expression (1)) and EVC in-

cylinder temperature TEVC determined through step S10 of Fig. 10, from the predetermined TFBYA-TEVC-SHEATR map shown in Fig. 21.

At step S17 of Fig. 11, a determination for
5   supercharging and choking phenomena regarding gas flow between intake and exhaust ports 5p and 6p via combustion chamber 3 during a valve overlap period, created by the pressure difference between the pressure in the intake port and the pressure in the exhaust port, is made.

10   At step S18, a check is made to determine whether a supercharging-phenomenon decision flag TBCRG is reset (=0). Concretely, when supercharging-phenomenon decision flag TBCRG is reset (=0), the ECU determines that the supercharging phenomenon regarding the gas flow between
15   intake and exhaust ports 5p and 6p via combustion chamber 3 during a valve overlap period, created by the pressure difference between the pressure in the intake port and the pressure in the exhaust port, does not take place. Conversely when supercharging-phenomenon decision flag TBCRG
20   is set (=1), the ECU determines that the supercharging phenomenon occurs. When the answer to step S18 is affirmative (YES), that is, in case of TBCRG=0, the routine proceeds from step S18 to step S19. Conversely when the answer to step S18 is negative (NO), that is, in case of
25   TBCRG=1, the routine proceeds from step S18 to step S22.

At step S19, a check is made to determine whether a choking-phenomenon decision flag CHOKE is reset (=0). When choking-phenomenon decision flag CHOKE is reset (=0), the ECU determines that the choking phenomenon regarding the gas
30   flow between intake and exhaust ports 5p and 6p via combustion chamber 3 during the valve overlap period, created by the pressure difference between the pressure in the intake port and the pressure in the exhaust port, does

not take place. Conversely when choking-phenomenon decision flag CHOKE is set (=1), the ECU determines that the choking phenomenon occurs. When the answer to step S19 is affirmative (YES), that is, in case of CHOKE=0, the routine

5   proceeds from step S19 to step S20, so as to calculate a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) suitable for an unsupercharged and unchoked state by using a temporary O/L period blow-back gas amount MRESOLtmp calculation routine shown in Fig. 13 (described

10 later). Conversely when the answer to step S19 is negative (NO), that is, in case of CHOKE=1, the routine proceeds from step S19 to step S21, so as to calculate a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) suitable for an unsupercharged and choked state by using a

15 temporary O/L period blow-back gas amount MRESOLtmp calculation routine shown in Fig. 14 (described later).

When the condition of TBCRG=1 is satisfied at step S18, at step S22 a check is made to determine whether choking-phenomenon decision flag CHOKE is reset (=0). When choking-

20 phenomenon decision flag CHOKE is reset (=0), the routine proceeds from step S22 to step S23, so as to calculate a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) suitable for a supercharged and unchoked state by using a temporary O/L period blow-back gas amount MRESOLtmp

25 calculation routine shown in Fig. 15 (described later). Conversely when choking-phenomenon decision flag CHOKE is set (=1), the routine proceeds from step S22 to step S24, so as to calculate a temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) suitable for a supercharged

30 and choked state by using a temporary O/L period blow-back gas amount MRESOLtmp calculation routine shown in Fig. 16 (described later).

After steps S20, S21, S23, or S24, the routine proceeds to step S25. At step S25, depending on the decision result of the presence or absence of the supercharging phenomenon and the presence or absence of the choking phenomenon, an O/L period blow-back gas amount MRESOL (unit: kg) is arithmetically calculated based on (i) temporary O/L period blow-back gas amount MRESOLtmp (unit: kg) properly calculated depending on both of supercharging-phenomenon decision flag TBCRG and choking-phenomenon decision flag CHOKE and (ii) O/L period integrated effective area ASUMOL, from the following physical expression (6).

$$MRESOL = (MRESOL_{tmp} \times ASUMOL \times 60)/(NRPM \times 360) \quad \cdots \cdots (6)$$

A way to determine the presence (TBCRG=1) or absence (TBCRG=0) of the supercharging phenomenon and the presence (CHOKE=1) or absence (CHOKE=0) of the choking phenomenon is hereunder described in detail by reference to the block diagram of Fig. 7 and the supercharging/choking phenomena determination routine of Fig. 12.

As seen from the block diagram of Fig. 7, the supercharging-and-choking phenomena determination section determines the presence (TBCRG=1) or absence (TBCRG=0) of the supercharging phenomenon and the presence (CHOKE=1) or absence (CHOKE=0) of the choking phenomenon, on the basis of the values SHEATR, PEVC, and PIN respectively calculated by the exhaust-gas ratio-of-specific-heat calculation section, the EVC in-cylinder pressure calculation section, and the intake pressure calculation section.

In more detail, at step S26 of Fig. 12, a pressure ratio PINBYEX of intake pressure to exhaust pressure is calculated based on both the intake pressure PIN detected based on a signal from intake pressure sensor 10 and EVC in-cylinder pressure PEVC calculated through step S11 of Fig. 10, from the following expression (7).

PINBYEX = PIN/PEVC $\cdots\cdots$(7)

At step S27, a check is made to determine whether the intake-pressure-to-exhaust-pressure ratio (simply, pressure ratio) PINBYEX is less than or equal to "1". The inequality PINBYEX≤1 means that the previously-noted supercharging phenomenon does not occur. On the contrary, the inequality PINBYEX>1 means that the previously-noted supercharging phenomenon occurs. When the answer to step S27 is affirmative (YES), that is, in case of PINBYEX≤1, the ECU determines that the supercharging phenomenon does not take place and thus the routine proceeds from step S27 to step S28. At step S28, supercharging-phenomenon decision flag TBCRG is reset to "0". After step S28, step S31 occurs. Conversely when the answer to step S27 is negative (NO), that is, in case of PINBYEX>1, the ECU determines that the supercharging phenomenon takes place and thus the routine proceeds from step S27 to step S29. At step S29, supercharging-phenomenon decision flag TBCRG is set to "1". After step S29, step S30 occurs. At step S30, exhaust-gas ratio-of-specific-heat SHEATR retrieved from the predetermined characteristic map of Fig. 21, is replaced with an air-fuel mixture ratio-of-specific-heat MIXAIRSHR, which is retrieved from the predetermined TFBYA-MIXAIRSHR characteristic map of Fig. 22 showing how an air-fuel mixture ratio-of-specific-heat MIXAIRSHR has to be varied relative to a target combustion equivalent ratio TFBYA. In the predetermined characteristic map shown in Fig. 22, the axis of abscissa of Fig. 22 indicates target combustion equivalent ratio TFBYA, whereas the axis of ordinate of Fig. 22 indicates air-fuel mixture ratio-of-specific-heat MIXAIRSHR. In the characteristic map of Fig. 22, the broken vertical line indicates a stoichiometric A/F ratio line that the desired A/F ratio is identical to the stoichiometric A/F

ratio (= 14.7) and thus target combustion equivalent ratio
TFBYA is "1". In Fig. 22, the right-hand side area
indicates a rich A/F mixture area, whereas the left-hand
side area indicates a lean A/F mixture area. As can be seen

5   from the predetermined characteristic map of Fig. 22, air-
fuel mixture ratio-of-specific-heat MIXAIRSHR tends to
gradually decrease, as target combustion equivalent ratio
TFBYA increases from a smaller value (a leaner mixture) via
"1" to a larger value (a richer mixture). Actually, air-

10 fuel mixture ratio-of-specific-heat MIXAIRSHR is map-
retrieved based on both of target combustion equivalent
ratio TFBYA calculated at step S2 of Fig. 8 (see the
expression (1)), from the predetermined TFBYA-MIXAIRSHR map
shown in Fig. 22. As discussed above, by way of replacement

15 of exhaust-gas ratio-of-specific-heat SHEATR by air-fuel
mixture ratio-of-specific-heat MIXAIRSHR through step S30 of
Fig. 12, it is possible to more precisely calculate the
internal EGR amount by switching or converting a ratio of
specific heat of gas passing through the previously-

20 described pseudo variable orifice from exhaust-gas ratio-of-
specific-heat SHEATR to air-fuel mixture ratio-of-specific-
heat MIXAIRSHR, even when a gas flows from intake port 5p
toward combustion chamber 3 and then blows from combustion
chamber 3 through exhaust port 6p owing to the supercharging

25 phenomenon, such as the supercharged state on turbocharged
engines or supercharged engines or inertia supercharging,
during a valve overlap period.

        At step S31, a low choking-phenomenon decision slice
level (or a minimum choking-phenomenon decision threshold

30 value) SLCHOKEL and a high choking-phenomenon decision slice
level (or a maximum choking-phenomenon decision threshold
value) SLCHOKEH are arithmetically calculated based on
exhaust-gas ratio-of-specific-heat SHEATR calculated through

step S16 of Fig. 11 or replaced with air-fuel mixture ratio-of-specific-heat MIXAIRSHR through step S30 of Fig. 12, from the following expressions (8) and (9).

$$\text{SLCHOKEL} = \{2/(\text{SHEATR}+1)\}^{\{\text{SHEATR}/(\text{SHEATR}-1)\}}$$

$$= \{2/(\text{SHEATR}+1)\}^{\wedge}\{\text{SHEATR}/(\text{SHEATR}-1)\} \cdots\cdots(8)$$

$$\text{SLCHOKEH} = \{2/(\text{SHEATR}+1)\}^{\{-\text{SHEATR}/(\text{SHEATR}-1)\}}$$

$$= \{2/(\text{SHEATR}+1)\}^{\wedge}\{-\text{SHEATR}/(\text{SHEATR}-1)\} \cdots\cdots(9)$$

As can be appreciated from the expression (8), a value {2/(SHEATR+1)} is raised to the index {SHEATR/(SHEATR-1)} to give minimum choking-phenomenon decision threshold value SLCHOKEL (^ means a power of the value {2/(SHEATR+1)}).

As can be appreciated from the expression (9), a value {2/(SHEATR+1)} is raised to the index {-SHEATR/(SHEATR-1)} to give maximum choking-phenomenon decision threshold value SLCHOKEH (^ means a power of the value {2/(SHEATR+1)}). As a matter of course, a computer must have an adequate capacity for arithmetically calculating a power of the value {2/(SHEATR+1)}. In case of computers having an inadequate capacity for calculating the power of the value {2/(SHEATR+1)}, minimum choking-phenomenon decision threshold value SLCHOKEL may be map-retrieved from a predetermined SHEATR-SLCHOKEL characteristic map showing how minimum choking-phenomenon decision threshold value SLCHOKEL has to be varied relative to exhaust-gas ratio-of-specific-heat SHEATR. In a similar manner, maximum choking-phenomenon decision threshold value SLCHOKEH may be map-retrieved from a predetermined SHEATR-SLCHOKEH characteristic map showing how maximum choking-phenomenon decision threshold value SLCHOKEH has to be varied relative to exhaust-gas ratio-of-specific-heat SHEATR.

The previously-discussed minimum choking-phenomenon decision threshold value SLCHOKEL and maximum choking-phenomenon decision threshold value SLCHOKEH correspond to

threshold limit values based on which the ECU determines
whether or not the choking phenomenon regarding gas flow
between intake and exhaust ports 5p and 6p via combustion
chamber 3 during a valve overlap period, created by the

5   pressure difference between intake and exhaust pressures,
takes place. As hereunder described in detail by reference
to step S32, intake-pressure-to-exhaust-pressure ratio
(pressure ratio) PINBYEX is compared to each of the minimum
and maximum choking-phenomenon decision threshold values

10 SLCHOKEL and SLCHOKEH. When either of (i) a condition that
pressure ratio PINBYEX is less than minimum choking-
phenomenon decision threshold value SLCHOKEL (i.e.,
PINBYEX<SLCHOKEL) and (ii) a condition that pressure ratio
PINBYEX is greater than maximum choking-phenomenon decision

15 threshold value SLCHOKEH (i.e., PINBYEX>SLCHOKEH) is
satisfied, the ECU determines that the choking phenomenon
takes place. On the contrary when pressure ratio PINBYEX is
greater than or equal to minimum choking-phenomenon decision
threshold value SLCHOKEL and pressure ratio PINBYEX is less

20 than or equal to maximum choking-phenomenon decision
threshold value SLCHOKEH (i.e., SLCHOKEL≤PINBYEX≤SLCHOKEH),
the ECU determines that the choking phenomenon does not take
place.

At step S32, a check is made to determine whether

25 pressure ratio PINBYEX is greater than or equal to minimum
choking-phenomenon decision threshold value SLCHOKEL and
additionally less than or equal to maximum choking-
phenomenon decision threshold value SLCHOKEH, that is to say,
SLCHOKEL≤PINBYEX≤SLCHOKEH. When the answer to step S32 is

30 affirmative, i.e., in case of SLCHOKEL≤PINBYEX≤SLCHOKEH, the
ECU determines that the choking phenomenon does not take
place, and thus the routine proceeds from step S32 to step
S33. At step S33, choking-phenomenon decision flag CHOKE is

At step S36, a pressure difference term MRSOLP needed for the arithmetic expression (12) (described later) for the unsupercharged and unchoked state, temporary O/L period blow-back gas amount MRESOLtmp calculation, is calculated based on exhaust-gas ratio-of-specific-heat SHEATR calculated through step S16 of Fig. 11 and intake-pressure-to-exhaust-pressure ratio (pressure ratio) PINBYEX calculated through step S26 of Fig. 12, from the following expression (11).

$$MRSOLP = SQRT[SHEATR/(SHEATR-1)$$
$$\times\{PINBYEX^{(2/SHEATR)}-PINBYEX^{((SHEATR+1)/SHEATR)}\}]$$
$$= SQRT[SHEATR/(SHEATR-1)\times\{PINBYEX^{(2/SHEATR)}-$$
$$PINBYEX^{((SHEATR+1)/SHEATR)}\}] \quad\cdots\cdots(11)$$

where SQRT denotes a coefficient for exhaust-gas gas constant REX and EVC in-cylinder temperature TEVC. In case of computers having an inadequate capacity for calculating the power of the value PINBYEX, pressure difference term MRSOLP may be map-retrieved from a predetermined SHEATR-PINBYEX-MRSOLP characteristic map showing how pressure difference term MRSOLP has to be varied relative to exhaust-gas ratio-of-specific-heat SHEATR and intake-pressure-to-exhaust-pressure ratio (pressure ratio) PINBYEX.

At step S37, the unsupercharged and unchoked state, temporary O/L period blow-back gas amount MRESOLtmp is calculated based on the EVC in-cylinder pressure PEVC calculated through step S11 of Fig. 10, density term MRSOLD calculated through step S35 of Fig. 13 and pressure difference term MRSOLP calculated through step S36 of Fig. 13, from the following expression (12).

$$MRESOLtmp = \sqrt{2}\times PEVC\times MRSOLD\times MRSOLP$$
$$\fallingdotseq 1.4\times PEVC\times MRSOLD\times MRSOLP \quad\cdots\cdots(12)$$

A way to calculate temporary valve overlap period blow-back gas amount MRESOLtmp (unit: kg) suitable for an

unsupercharged and choked state (relating to step S21 of Fig. 11) is hereunder explained by reference to the unsupercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp calculation routine shown in Fig.

5   14.

At step S38 of Fig. 14, in the same manner as step S35 of Fig. 13, a density term MRSOLD needed for an arithmetic expression (14) (described later) suited to the unsupercharged and choked state, temporary O/L period blow-

10   back gas amount MRESOLtmp calculation, is calculated based on exhaust-gas gas constant REX (unit: J/kgK) and EVC in-cylinder temperature TEVC, from the previously-noted expression (10), that is, MRSOLD = SQRT{1/(REX×TEVC)}.

At step S39, a pressure difference term MRSOLPC needed

15   for the arithmetic expression (14) (described later) suited to the unsupercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp calculation, is calculated based on exhaust-gas ratio-of-specific-heat SHEATR calculated through step S16 of Fig. 11, from the following

20   expression (13).

$$MRSOLPC = SQRT[SHEATR \times \{2/(SHEATR+1)\}^{\{(SHEATR+1)/(SHEATR-1)\}}]$$

$$= SQRT[SHEATR \times \{2/(SHEATR+1)\}^{\{(SHEATR+1)/(SHEATR-1)\}}]$$

$$\cdots \cdots (13)$$

where SQRT denotes a coefficient for exhaust-gas gas

25   constant REX and EVC in-cylinder temperature TEVC. In case of computers having an inadequate capacity for calculating the power of the value {2/(SHEATR+1)}, pressure difference term MRSOLPC may be map-retrieved from a predetermined SHEATR-MRSOLPC characteristic map showing how pressure

30   difference term MRSOLPC has to be varied relative to exhaust-gas ratio-of-specific-heat SHEATR.

At step S40, the unsupercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp is

calculated based on the EVC in-cylinder pressure PEVC calculated through step S11 of Fig. 10, density term MRSOLD calculated through step S38 of Fig. 14 and pressure difference term MRSOLPC calculated through step S39 of Fig.

5 14, from the following expression (14).

$$MRESOL_{tmp} = PEVC \times MRSOLD \times MRSOLPC \quad \cdots\cdots(14)$$

A way to calculate temporary valve overlap period blow-back gas amount $MRESOL_{tmp}$ (unit: kg) suitable for a supercharged and unchoked state (relating to step S23 of Fig.

10 11) is hereunder explained by reference to the supercharged and unchoked state, temporary O/L period blow-back gas amount $MRESOL_{tmp}$ calculation routine shown in Fig. 15.

At step S41 of Fig. 15, a pressure difference term MRSOLPT needed for an arithmetic expression (16) (described

15 later) suited to the supercharged and unchoked state, temporary O/L period blow-back gas amount $MRESOL_{tmp}$ calculation, is calculated based on exhaust-gas ratio-of-specific-heat SHEATR (replaced with air-fuel mixture ratio-of-specific-heat MIXAIRSHR through step S30 of Fig. 12) and

20 intake-pressure-to-exhaust-pressure ratio (pressure ratio) PINBYEX calculated through step S26 of Fig. 12, from the following expression (15).

$$MRSOLPT = SQRT[SHEATR/(SHEATR-1)$$
$$\times \{PINBYEX^{(-2/SHEATR)} - PINBYEX^{(-(SHEATR+1)/SHEATR)}\}]$$

25
$$= SQRT[SHEATR/(SHEATR-1) \times \{PINBYEX^\wedge(-2/SHEATR) -$$
$$PINBYEX^\wedge(-(SHEATR+1)/SHEATR)\}] \quad \cdots\cdots(15)$$

where SQRT denotes a coefficient for exhaust-gas gas constant REX and EVC in-cylinder temperature TEVC. In case of computers having an inadequate capacity for calculating

30 the power of the value PINBYEX, pressure difference term MRSOLPT may be map-retrieved from a predetermined SHEATR-PINBYEX-MRSOLPT characteristic map showing how pressure difference term MRSOLPT has to be varied relative to

exhaust-gas ratio-of-specific-heat SHEATR (replaced by air-fuel mixture ratio-of-specific-heat MIXAIRSHR) and intake-pressure-to-exhaust-pressure ratio (pressure ratio) PINBYEX.

At step S42, the supercharged and unchoked state,

5   temporary O/L period blow-back gas amount MRESOLtmp is calculated based on the intake pressure PIN detected based on a signal from intake pressure sensor 10 and pressure difference term MRSOLPT (calculated through step S41 of Fig. 15) for the supercharged and unchoked state, from the

10   following expression (16).

$$MRESOLtmp = -\sqrt{2} \times \sqrt{\frac{1}{RIN \times TIN}} \times PIN \times MRSOLPT$$

$$= -\sqrt{2} \times \sqrt{\frac{1}{0.287 \times 300}} \times PIN \times MRSOLPT$$

$$\fallingdotseq -0.152 \times PIN \times MRSOLPT \quad \cdots \cdots (16)$$

where RIN denotes a gas constant of intake air (fresh air),

15   and TIN denotes a Kelvin absolute temperature of the intake air, and 300K is almost equal to 27°C (= (273+27)K = 300K). As can be seen from the minus sign indicated in the expression (16), the supercharged and unchoked state, temporary O/L period blow-back gas amount MRESOLtmp is

20   calculated as a negative value. As previously discussed, the value of O/L period blow-back gas amount MRESOL (MRESOLtmp) is defined as a positive value when a gas flows from exhaust port 6p toward combustion chamber 3 and then blows from combustion chamber 3 back to intake port 5p

25   during a valve overlap period, and defined as a negative value when a gas flows from intake port 5p toward combustion chamber 3 and then blows from combustion chamber 3 through exhaust port 6p during a valve overlap period. Thus, the supercharged and unchoked state, temporary O/L period blow-

30   back gas amount MRESOLtmp, calculated as a negative value by the expression (16), means the amount of gas that flows from

intake port 5p toward combustion chamber 3 and then blows from combustion chamber 3 through exhaust port 6p during a valve overlap period. In this case (in the supercharged and unchoked state), the internal EGR amount is reduced by

5 temporary O/L period blow-back gas amount MRESOLtmp calculated by the expression (16).

A way to calculate temporary O/L period blow-back gas amount MRESOLtmp (unit: kg) suitable for a supercharged and choked state (relating to step S24 of Fig. 11) is hereunder

10 explained by reference to the supercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp calculation routine shown in Fig. 16.

At step S43 of Fig. 16, in a similar manner to step S39 of Fig. 14, a pressure difference term MRSOLPC needed for an

15 arithmetic expression (17) (described later) suited to the supercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp calculation, is calculated based on exhaust-gas ratio-of-specific-heat SHEATR (replaced with air-fuel mixture ratio-of-specific-heat MIXAIRSHR through

20 step S30 of Fig. 12), from the aforementioned expression (13), that is, MRSOLPC = SQRT[SHEATR×{2/(SHEATR+1)}^{(SHEATR+1)/(SHEATR-1)}]. In case of computers having an inadequate capacity for calculating the power of the value {2/(SHEATR+1)}, pressure

25 difference term MRSOLPC may be map-retrieved from a predetermined SHEATR-MRSOLPC characteristic map showing how pressure difference term MRSOLPC has to be varied relative to exhaust-gas ratio-of-specific-heat SHEATR (replaced by air-fuel mixture ratio-of-specific-heat MIXAIRSHR).

30 At step S44, the supercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp is calculated based on the intake pressure PIN detected based on a signal from intake pressure sensor 10 and pressure

difference term MRSOLPC (calculated through step S43 of Fig. 16) for the supercharged and choked state, from the following expression (17).

$$MRESOLtmp = -\sqrt{\frac{1}{RIN \times TIN}} \times PIN \times MRSOLPC$$

$$= -\sqrt{\frac{1}{0.287 \times 300}} \times PIN \times MRSOLPC$$

$$\fallingdotseq -0.108 \times PIN \times MRSOLPC \quad \cdots \cdots (17)$$

where RIN denotes a gas constant of intake air (fresh air), and TIN denotes a Kelvin absolute temperature of intake air, and 300K is almost equal to 27°C (= (273+27)K = 300K). As can be seen from the minus sign indicated in the expression (17), the supercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp is calculated as a negative value. Thus, the supercharged and choked state, temporary O/L period blow-back gas amount MRESOLtmp, calculated as a negative value by the expression (17), means the amount of gas that flows from intake port 5p toward combustion chamber 3 and then blows from combustion chamber 3 through exhaust port 6p during a valve overlap period. In this case (in the supercharged and choked state), the internal EGR amount is reduced by temporary O/L period blow-back gas amount MRESOLtmp calculated by the expression (17).

As set forth above, through steps S20, 21, 23, and 24 of Fig. 11, temporary O/L period blow-back gas amount MRESOLtmp is properly accurately calculated depending on the presence (TBCRG=1) or absence (TBCRG=0) of the supercharging phenomenon regarding gas flow between intake and exhaust ports 5p and 6p via combustion chamber 3 during a valve overlap period, created by the pressure difference between the pressure in the intake port and the pressure in the exhaust port, and the presence (CHOKE=1) or absence (CHOKE=0) of the choking phenomenon regarding the gas flow

between intake and exhaust ports 5p and 6p via combustion chamber 3 during the valve overlap period, created by the pressure difference between the pressure in the intake port and the pressure in the exhaust port. Thereafter steps S20, 21, 23, or 24, temporary O/L period blow-back gas amount MRESOL is arithmetically calculated through step S25 (see Fig. 11), based on (i) temporary O/L period blow-back gas amount MRESOLtmp (unit: kg) properly calculated depending on both of supercharging-phenomenon decision flag TBCRG and choking-phenomenon decision flag CHOKE, and (ii) O/L period integrated effective area ASUMOL. Then, the internal EGR calculation routine proceeds from step S6 to step S7 (see Fig. 9) to arithmetically calculate internal EGR amount per cylinder MRES (unit: kg). Thereafter, the routine proceeds from step S3 to step S4 (see Fig. 8) to arithmetically calculate internal EGR ratio MRESFR (unit: %).

A way to calculate EVC in-cylinder volumetric capacity VEVC (relating to step S8 of Fig. 10) is hereunder described in detail by reference to the block diagram of Fig. 23 and the EVC in-cylinder volumetric capacity VEVC (unit: m^3) calculation routine of Fig. 29.

As seen from the block diagram of Fig. 23, the EVC in-cylinder volumetric capacity calculation section calculates EVC in-cylinder volumetric capacity VEVC (unit: m^3), which is geometrically determined based on the position of reciprocating piston 2 at the exhaust valve closure timing EVC, on the basis of the variation VTEOFS of exhaust valve closure timing EVC (hereinafter is referred to as "EVC variation VTEOFS"). The EVC variation VTEOFS is calculated by an EVC variation calculation section whose operation will be fully described later by reference to the flow chart shown in Fig. 30. As seen from the flow chart of Fig. 29, at step S45, EVC variation VTEOFS is calculated in

accordance with the flow chart shown in Fig. 30. The positive sign of EVC variation VTEOFS is defined as a valve overlap (O/L) increase direction, that is, an EVC retard direction, whereas the negative sign of EVC variation VTEOFS

5   is defined as an O/L decrease direction, that is, an EVC advance direction. At step S46 of Fig. 29, EVC in-cylinder volumetric capacity VEVC is retrieved based on EVC variation VTEOFS from the predetermined VTEOFS-VEVC lookup table of Fig. 17.

10   A way to calculate EVC variation VTEOFS (relating to step S45 of Fig. 29) is hereunder explained by reference to the block diagram of Fig. 24 and the EVC variation VTEOFS calculation routine of Fig. 30.

As seen from the block diagram of Fig. 24, a basic EVC

15   variation calculation section calculates a basic EVC variation VTCNOWE (a variation of angular phase of the exhaust camshaft relative to the engine crankshaft), based on latest up-to-date information regarding the relative position of the engine crankshaft, detected based on a

20   signal from crank angle sensor 14, and the cam angle of the exhaust camshaft, detected based on a signal from exhaust-valve cam angle sensor 17. An exhaust-valve-temperature dependent EVC variation correction value calculation section calculates an exhaust-valve-temperature dependent EVC

25   variation correction value VTCLE based on an exhaust valve clearance VCLE that is calculated or estimated by an exhaust valve clearance calculation section (or an exhaust valve clearance estimation section). An EVC-correction learned value calculation section (exactly, a valve-train component-

30   parts wear dependent EVC-correction learned value calculation section) calculates an EVC-correction learned value (exactly, a valve-train component-parts wear dependent EVC-correction learned value) VTHOSE, which will be fully

described later by reference to the flow chart shown in Fig. 32. A final EVC variation calculation section calculates EVC variation VTEOFS based on basic EVC variation VTCNOWE, exhaust-valve-temperature dependent EVC variation correction value VTCLE, and EVC-correction learned value VTHOSE. In more detail, at step S47 of Fig. 30, basic EVC variation VTCNOWE is calculated based on the signals from crank angle sensor 14 and exhaust-valve cam angle sensor 17. At step S48, exhaust valve clearance VCLE is estimated or calculated in accordance with the flow chart of Fig. 31 (described later). At step S49, exhaust-valve-temperature dependent EVC variation correction value VTCLE is based on exhaust valve clearance VCLE from a predetermined VCLE-VTCLE lookup table of Fig. 36A showing how an exhaust-valve-temperature dependent EVC variation correction value VTCLE has to be varied relative to an exhaust valve clearance VCLE. More concretely, in the lookup table of Fig. 36A, the vertical broken line indicates a reference exhaust valve clearance line at the steady state, the axis of abscissa of Fig. 36A indicates exhaust valve clearance VCLE, and the axis of ordinate of Fig. 36A indicates an exhaust-valve-temperature dependent EVC variation correction value VTCLE, that is, a deviation from an exhaust valve closure timing EVC corresponding to the steady-state reference exhaust valve clearance. As can be seen from the VCLE-VTCLE lookup table of Fig. 36A, when exhaust valve clearance VCLE of exhaust valve 6 decreases owing to a rise in an exhaust valve temperature VTMPE (see the left-hand characteristic curve of the steady-state reference exhaust valve clearance line), the actual exhaust valve closure timing tends to phase-retard by a phase angle corresponding to exhaust-valve-temperature dependent EVC variation correction value VTCLE. The phase retard of the actual EVC means an increase in the

valve overlap, and thus the exhaust-valve-temperature
dependent EVC variation is increasingly compensated for
based on a minus deviation of exhaust valve clearance VCLE
from the steady-state reference exhaust valve clearance, in
5   accordance with the characteristic curve of Fig. 36A.
Conversely when exhaust valve clearance VCLE increases owing
to a drop in exhaust valve temperature VTMPE (see the right-
hand characteristic curve of the steady-state reference
exhaust valve clearance line), the actual exhaust valve
10 closure timing tends to phase-advance by a phase angle
corresponding to exhaust-valve-temperature dependent EVC
variation correction value VTCLE. The phase advance of the
actual EVC means a decrease in the valve overlap, and thus
the exhaust-valve-temperature dependent EVC variation is
15 decreasingly compensated for based on a plus deviation of
exhaust valve clearance VCLE from the steady-state reference
exhaust valve clearance, in accordance with the
characteristic curve of Fig. 36A.

        At step S50 of Fig. 30, EVC variation learned value
20 VTHOSE is calculated in accordance with the flow chart of
Fig. 32. Then, at step S51, EVC variation VTEOFS is
calculated based on (i) basic EVC variation VTCNOWE, (ii)
exhaust-valve-temperature dependent EVC variation correction
value VTCLE, which is calculated or retrieved based on a
25 change in exhaust valve clearance VCLE, arising from a
change in exhaust valve temperature VTMPE, and (iii) EVC-
correction learned value VTHOSE, which is calculated based
on a learned value for a change in exhaust valve clearance
VCLE, arising from valve-train component-parts wear such as
30 exhaust cam wear and shim wear, from the following
expression (18).

        VTEOFS = VTCNOWE + VTCLE + VTHOSE $\cdots\cdots$(18)

A way to calculate exhaust valve clearance VCLE (relating to step S48 of Fig. 30) is hereunder explained by reference to the block diagram of Fig. 25 and the valve clearance calculation routine of Fig. 31.

5   As seen from the block diagram of Fig. 25, a valve temperature calculation section calculates or estimates exhaust valve temperature VTMPE (intake valve temperature VTMPI) based on a fuel injection amount correlated to engine load (see the lookup tables shown in Figs. 37A and 37B) that

10   is determined based on the intake-air quantity per cylinder (the fresh-air quantity per cylinder) MACYL computed based on the intake-air quantity measured by airflow meter 9. The valve clearance calculation section (or the valve clearance estimation section) calculates or estimates exhaust valve

15   clearance VCLE (intake valve clearance VCLI) based on exhaust valve temperature VTMPE (intake valve temperature VTMPI). In the shown embodiment, although exhaust valve temperature VTMPE (intake valve temperature VTMPI) is map-retrieved based on the fuel injection amount (estimated

20   based on the intake-air quantity per cylinder MACYL), in lieu thereof exhaust valve temperature VTMPE (intake valve temperature VTMPI) may be sensed or detected by means of a temperature sensor that directly senses an exhaust valve temperature (an intake valve temperature). In more detail,

25   as seen from the flow chart of Fig. 31, at step S52, exhaust valve temperature VTMPE is calculated or retrieved based on the fuel injection amount from the predetermined steady-state exhaust valve temperature VTMPE lookup table of Fig. 37A how an exhaust valve temperature VTMPE has to be varied

30   relative to a fuel injection amount. In a similar manner, at step S52, an intake valve temperature VTMPI is also calculated or retrieved based on the fuel injection amount from a predetermined steady-state intake valve temperature

VTMPI lookup table of Fig. 37B how an intake valve temperature VTMPI has to be varied relative to a fuel injection amount (regarded as an engine load). The axis of abscissa of Fig. 37A indicates a fuel injection amount,

5   whereas the axis of ordinate of Fig. 37A indicates exhaust valve temperature VTMPE correlated to engine load. The axis of abscissa of Fig. 37B indicates a fuel injection amount, whereas the axis of ordinate of Fig. 37B indicates intake valve temperature VTMPI correlated to engine load. As can

10   be seen from the characteristic curves shown in Figs. 37A and 37B, intake and exhaust valve temperatures VTMPI and VTMPE tend to rise, as the fuel injection amount increases. In order to compute or calculate a final fuel injection amount TI for fuel injection control, first, a basic fuel

15   injection amount TP (corresponding to a stoichiometric A/F ratio) is calculated from the expression TP=K×MACYL/NRPM, where K is a constant, MACYL denotes the intake-air quantity per cylinder monitored by airflow meter 9 and NRPM denotes the engine speed detected by crank angle sensor 14. Final

20   fuel injection amount TI is calculated by compensating for basic fuel injection amount TP depending on at least one of target combustion equivalent ratio TFBYA and an A/F feedback correction coefficient LAMBDA as follows.

TI = TP×TFBYA×LAMBDA ·····(19)

25   At step S53 of Fig. 31, a temporary exhaust valve clearance VCLEtmp is arithmetically calculated based on exhaust valve temperature VTMPE from the following expression (20).

VCLEtmp = -KVTMPE×(VTMPE-90)+VCLSTDE ·····(20)

30   where -KVTMPE denotes a coefficient determined depending on a material and of exhaust valve 6 and a length of the exhaust valve stem, mainly taking into account an amount of thermal expansion of the exhaust valve stem in the axial

direction of exhaust valve 6 but not taking into account of
an amount of thermal expansion of the engine cylinder head
and the like, and VCLSTDE denotes a reference exhaust valve
clearance at a predetermined reference exhaust valve

5   temperature of 90°C, and thus {-KVTMPE×(VTMPE-90)} means a
decrease in the exhaust valve clearance, arising from the
rise in exhaust valve temperature VTMPE from the
predetermined reference exhaust valve temperature of 90°C.
As can be appreciated from the expression (20), temporary

10   exhaust valve clearance VCLEtmp tends to reduce, as exhaust
valve temperature VTMPE rises.

       In the same manner as temporary exhaust valve clearance
VCLEtmp, at step S53 of Fig. 31, a temporary intake valve
clearance VCLItmp is arithmetically calculated based on

15   intake valve temperature VTMPI from the following expression
(21).

       VCLItmp = -KVTMPI×(VTMPI-90)+VCLSTDI ·····(21)
where -KVTMPI denotes a coefficient determined depending on
a material and of intake valve 5 and a length of the intake

20   valve stem, mainly taking into account an amount of thermal
expansion of the intake valve stem in the axial direction of
intake valve 5 but not taking into account of an amount of
thermal expansion of the engine cylinder head and the like,
and VCLSTDI denotes a reference intake valve clearance at a

25   predetermined reference intake valve temperature of 90°C,
and thus {-KVTMPI×(VTMPI-90)} means a decrease in the intake
valve clearance, arising from the rise in intake valve
temperature VTMPI from the predetermined reference intake
valve temperature of 90°C. As can be appreciated from the

30   above expression (21), temporary intake valve clearance
VCLItmp tends to reduce, as intake valve temperature VTMPI
rises.

At step S54 of Fig. 31, a check is made to determine whether temporary exhaust valve clearance VCLEtmp is greater than or equal to "0". When the answer to step S54 is affirmative (YES), i.e., in case of VCLEtmp≥0, the routine

5　proceeds from step S54 to step S56. Conversely when the answer to step S54 is negative (NO), i.e., in case of VCLEtmp<0, the routine proceeds from step S54 to step S55. At step S55, temporary exhaust valve clearance VCLEtmp is set to "0", that is, VCLEtmp=0. Thereafter, the routine flows

10　from step S55 to S56. At step S56, exhaust valve clearance VCLE is replaced with temporary exhaust valve clearance VCLEtmp, that is, VCLE=VCLEtmp. A series of steps S52-S56 of Fig. 31, are necessary to set exhaust valve clearance VCLE to a value greater than or equal to "0", since exhaust valve

15　clearance VCLE never becomes a negative value. A series of steps S52-S56 of Fig. 31, are also necessary to set intake valve clearance VCLI to a value greater than or equal to "0", since intake valve clearance VCLI never becomes a negative value.

20　　A way to calculate EVC-correction learned value VTHOSE (relating to step S50 of Fig. 30) is hereunder explained by reference to the block diagram of Fig. 26 and the valve-timing-correction learned value (in particular, EVC-correction learned value VTHOSE) calculation routine of Fig.

25　32.

　　As seen from the block diagram of Fig. 26, the basic valve-timing variation calculation section calculates the basic valve-timing variation VTCNOWE (VTCNOW), that is, a variation of angular phase of the exhaust camshaft relative

30　to the engine crankshaft (a variation of angular phase of the intake camshaft relative to the engine crankshaft), based on latest up-to-date information regarding the relative position of the engine crankshaft, detected based

on a signal from crank angle sensor 14, and the cam angle of
the exhaust camshaft (the intake camshaft), detected based
on a signal from exhaust-valve cam angle sensor 17 (exhaust-
valve cam angle sensor 16). The valve-temperature dependent

5   valve-timing variation correction value calculation section
calculates exhaust-valve-temperature dependent EVC variation
correction value VTCLE based on exhaust valve clearance VCLE
(intake-valve-temperature dependent IVO variation correction
value VTCLI based on intake valve clearance VCLI). A valve-

10 timing estimate calculation section calculates or estimates
an EVC estimate VCLTEE based on both of basic EVC variation
VTCNOWE and exhaust-valve-temperature dependent EVC
variation correction value VTCLE (an IVO estimate VCLTEI
based on both of basic IVO variation VTCNOW and intake-

15 valve-temperature dependent IVO variation correction value
VTCLI). On the other hand, a valve-timing real value
calculation section calculates an EVC real value VCLTRE (an
IVO real value VCLTRI) based on latest up-to-date
information regarding the relative position of the engine

20 crankshaft, detected based on a signal from crank angle
sensor 14, and the frequency of oscillatory seating motion
of exhaust valve 6 (intake valve 5), detected based on a
signal from knock sensor 25, taking into account the
decision result of a valve-timing real value decision

25 section (exactly, a valve-timing real value calculation
enabling-condition decision section, which will be fully
described in detail by reference to the flow chart of Fig.
33). Finally, the valve-timing-correction learned value
calculation section calculates the valve-timing-correction

30 learned value (exactly, the valve-train component-parts wear
dependent valve-timing-correction learned value) VTHOSE
(VTHOSI), based on both of valve-timing estimate VCLTEE
(VCLTEI) and valve-timing real value VCLTRE (VCLTRI). In

more detail, at step S57 of Fig. 32, a valve timing real

value calculation enabling flag (an EVC real value

calculation enabling flag FVTHOSE and an IVO real value

calculation enabling flag FVTHOSI) is calculated (set or

5   reset) in accordance with the flow chart shown in Fig. 33

(described later). At step S58, a check is made to

determine whether the valve timing real value calculation

enabling flag (each of EVC real value calculation enabling

flag FVTHOSE and IVO real value calculation enabling flag

10   FVTHOSI) is set to "1". The result of step S58 is used to

determine whether the engine is conditioned in the valve

timing detectable engine operating state suited to precisely

detect or extract EVC real value VCLTRE (IVO real value

VCLTRI). When EVC real value calculation enabling flag

15   FVTHOSE (IVO real value calculation enabling flag FVTHOSI)

is set to "1", the routine proceeds from step S58 to step

S59. Conversely when EVC real value calculation enabling

flag FVTHOSE (IVO real value calculation enabling

FVTHOSI) is reset to "0", one execution cycle of the routine

20   of Fig. 32 terminates. At step S59, the actual valve-

seating timing of exhaust valve 6 (the actual valve-seating

timing of intake valve 5), in other words, EVC real value

VCLTRE (IVO real value VCLTRI) is calculated based on latest

up-to-date information regarding the relative position of

25   the engine crankshaft, detected based on a signal from crank

angle sensor 14, and the frequency of oscillatory seating

motion of exhaust valve 6 (intake valve 5), detected based

on a signal from knock sensor 25. At step S60, EVC estimate

VCLTEE (IVO estimate VCLTEI) is arithmetically calculated

30   based on both of a reference exhaust valve closure timing

VCLTSTDE (a reference intake valve open timing VCLTSTDI) and

exhaust-valve-temperature dependent EVC variation correction

value VTCLE (intake-valve-temperature dependent IVO

variation correction value VTCLI), from the expression (22) (the expression (23)).

$$VCLTEE = VCLTSTDE + VTCLE \ (degATDC) \cdots (21)$$

$$VCLTEI = VCLTSTDI + VTCLI \ (degATDC) \cdots (23)$$

5   where reference exhaust valve closure timing VCLTSTDE means an exhaust valve closure timing obtained when basic EVC variation VTCNOWE is zero at reference exhaust valve clearance VCLSTDE, and reference intake valve open timing VCLTSTDI means an intake valve open timing obtained when

10 basic IVO variation VTCNOW is zero at reference intake valve clearance VCLSTDI.

At step S61 of Fig. 32, a temporary EVC-correction learned value $VTHOSEtmp$ is calculated as a difference or a valve timing error (VCLTRE-VCLTEE) between EVC real value

15 VCLTRE and EVC estimate VCLTEE, that is, $VTHOSEtmp=VCLTRE-VCLTEE$. In a similar manner, a temporary IVO-correction learned value $VTHOSItmp$ is calculated as a difference (VCLTRI-VCLTEI) between IVO real value VCLTRI and IVO estimate VCLTEI, that is, $VTHOSItmp=VCLTRI-VCLTEI$.

20 At step S62, a check is made to determine whether the absolute value $|VTHOSEtmp-VTHOSE|$ of a deviation of temporary EVC-correction learned value $VTHOSEtmp$ from the current value of EVC-correction learned value VTHOSE is greater than or equal to a predetermined threshold value SLVCL. When the

25 answer to step S62 is affirmative (YES), that is, in case of $|VTHOSEtmp-VTHOSE| \geq SLVCL$, the routine proceeds from step S62 to step S63. On the contrary when the answer to step S62 is negative (NO), that is, in case of $|VTHOSEtmp-VTHOSE| < SLVCL$, one execution cycle of the routine of Fig. 32 terminates.

30 The condition defined by the inequality $|VTHOSEtmp-VTHOSE| \geq SLVCL$ means that motion-transmitting valve-train component parts wear such as cam and shim wear develops considerably. Thus, at step S63, EVC-correction learned

value VTHOSE is updated by substituting temporary EVC-
correction learned value VTHOSEtmp for EVC-correction learned
value VTHOSE, that is, VTHOSE=VTHOSEtmp. When exhaust valve
clearance VCLE of exhaust valve 6 increases owing to an

5   increase in exhaust cam and shim wear, the actual exhaust
valve closure timing tends to phase-advance. The phase
advance of the actual EVC means a decrease in the valve
overlap, in other words, a negative EVC variation.

       In a similar manner, at step S62, a check is made to

10   determine whether the absolute value $|VTHOSItmp-VTHOSI|$ of a
deviation of temporary IVO-correction learned value VTHOSItmp
from the current value of IVO-correction learned value
VTHOSI is greater than or equal to predetermined threshold
value SLVCL. When the answer to step S62 is affirmative

15   (YES), that is, in case of $|VTHOSItmp-VTHOSI| \geq SLVCL$, the
routine proceeds from step S62 to step S63. On the contrary
when the answer to step S62 is negative (NO), that is, in
case of $|VTHOSItmp-VTHOSI| < SLVCL$, one execution cycle of the
routine of Fig. 32 terminates. The condition defined by the

20   inequality $|VTHOSItmp-VTHOSI| \geq SLVCL$ means that motion-
transmitting valve-train component parts wear such as cam
and shim wear develops considerably. Thus, at step S63,
IVO-correction learned value VTHOSI is updated by
substituting temporary IVO-correction learned value VTHOSItmp

25   for IVO-correction learned value VTHOSI, that is,
VTHOSI=VTHOSItmp. When intake valve clearance VCLI of intake
valve 5 increases owing to an increase in intake cam and
shim wear, the actual intake valve open timing tends to
phase-retard. The phase retard of the actual IVO means a

30   decrease in the valve overlap, in other words, a negative
IVO variation.

       A way to calculate the valve timing real value
calculation enabling flag, i.e., EVC real value calculation

enabling flag FVTHOSE and IVO real value calculation
enabling flag FVTHOSI (relating to step S57 of Fig. 32) is
hereunder explained by reference to the valve timing real
value calculation enabling flag (EVC real value calculation
5   enabling flag FVTHOSE and IVO real value calculation
enabling flag FVTHOSI) calculation routine shown in Fig. 33.

At step S64 of Fig. 33, a check is made to determine
whether the basic valve timing variation, namely, basic EVC
variation VTCNOWE (basic IVO variation VTCNOW) is "0", that
10   is, VTCNOWE=0 (VTCNOW=0).

At step S65, a check is made to determine whether the
engine temperature, namely, engine coolant temperature Tw is
greater than or equal to a predetermined temperature value
VTHOSTW, that is, Tw≥VTHOSTW.

15   At step S66, a check is made to determine whether the
engine speed NRPM is less than or equal to a predetermined
speed value VTHOSNE, that is, NRPM≤VTHOSNE.

At step S67, a check is made to determine whether the
throttle opening TVO is less than or equal to a
20   predetermined throttle opening VTHOSTVO, that is,
TVO≤VTHOSTVO. Throttle opening TVO is computed or estimated
based on a signal from the ECU to the throttle actuator of
electronically-controlled throttle valve 19.

When the answers to steps S64-S67 are all in the
25   affirmative (YES), that is, the conditions defined by
VTCNOWE=0 (VTCNOW=0), Tw≥VTHOSTW, NRPM≤VTHOSNE, and
TVO≤VTHOSTVO are all satisfied, the routine proceeds to step
S68. Satisfying all of the conditions defined by VTCNOWE=0
(VTCNOW=0), Tw≥VTHOSTW, NRPM≤VTHOSNE, and TVO≤VTHOSTVO means
30   that the engine is conditioned in the valve timing
detectable engine operating state suited to precisely detect
or extract EVC real value VCLTRE (IVO real value VCLTRI).
Thus, at step S68, EVC real value calculation enabling flag

FVTHOSE (IVO real value calculation enabling flag FVTHOSI) is set to "1", that is, FVTHOSE=1 (FVTHOSI=1). Conversely when at least one of the answers to steps S64-S67 is in the negative (NO), that is, at least one of the conditions

5   defined by VTCNOWE=0 (VTCNOW=0), Tw≥VTHOSTW, NRPM≤VTHOSNE, and TVO≤VTHOSTVO is unsatisfied, the routine proceeds to step S69. Unsatisfying at least one of the conditions defined by VTCNOWE=0 (VTCNOW=0), Tw≥VTHOSTW, NRPM≤VTHOSNE, and TVO≤VTHOSTVO means that the engine is not conditioned in

10   the valve timing detectable engine operating state suitable for precise detection or extraction of EVC real value VCLTRE (IVO real value VCLTRI). Thus, at step S69, EVC real value calculation enabling flag FVTHOSE (IVO real value calculation enabling flag FVTHOSI) is reset to "0", that is,

15   FVTHOSE=0 (FVTHOSI=0).

       A way to calculate O/L period integrated effective area ASUMOL (relating to step S14 of Fig. 11) is hereunder described in detail by reference to the block diagram of Fig. 27 and the O/L period integrated effective area ASUMOL

20   (unit: m^3) calculation routine of Fig. 34.

       As seen from the block diagram of Fig. 27, the O/L period integrated effective area ASUMOL calculation section arithmetically calculates O/L period integrated effective area ASUMOL based on the calculated values, namely the

25   variation VTIOFS of intake valve open timing IVO calculated by the IVO variation VTIOFS calculation section and the variation VTEOFS of exhaust valve closure timing EVC calculated by the EVC variation VTEOFS calculation section. In more detail, at step S70 of Fig. 34 IVO variation VTIOFS

30   is calculated in accordance with the flow chart shown in Fig. 35. In a similar manner to step S70, at step S71 EVC variation VTEOFS is calculated in accordance with the flow chart shown in Fig. 30. Lastly at step S72, O/L period

integrated effective area ASUMOL is determined based on both of IVO variation VTIOFS and EVC variation VTEOFS, from a predetermined VTIOFS-VTEOFS-ASUMOL characteristic map shown in Fig. 38. The axis of abscissa of Fig. 38 indicates an

5   IVO variation VTIOFS, whereas the axis of ordinate of Fig. 38 indicates an EVC variation VTEOFS. As can be seen from the characteristic map of Fig. 38, O/L period integrated effective area ASUMOL, that is, the variation VTCOL of valve overlap O/L, tends to increase, as at least one of IVO

10   variation VTIOFS and EVC variation VTEOFS increases.

A way to calculate IVO variation VTIOFS (relating to step S70 of Fig. 34) is hereunder explained by reference to the block diagram of Fig. 28 and the IVO variation VTIOFS calculation routine of Fig. 35.

15   As seen from the block diagram of Fig. 28, a basic IVO variation calculation section calculates a basic IVO variation VTCNOW (a variation of angular phase of the intake camshaft relative to the engine crankshaft), based on latest up-to-date information regarding the relative position of

20   the engine crankshaft, detected based on a signal from crank angle sensor 14, and the cam angle of the intake camshaft, detected based on a signal from intake-valve cam angle sensor 16. An intake-valve-temperature dependent IVO variation correction value calculation section calculates an

25   intake-valve-temperature dependent IVO variation correction value VTCLI based on an intake valve clearance VCLI that is calculated or estimated by an intake valve clearance calculation section (or an intake valve clearance estimation section). An IVO-correction learned value calculation

30   section (exactly, a valve-train component-parts wear dependent IVO-correction learned value calculation section) calculates an IVO-correction learned value (exactly, a valve-train component-parts wear dependent IVO-correction

learned value) VTHOSI (see the flow chart shown in Fig. 32).
A final IVO variation calculation section calculates IVO
variation VTIOFS based on basic IVO variation VTCNOW,
intake-valve-temperature dependent IVO variation correction

5   value VTCLI, and IVO-correction learned value VTHOSI. In
more detail, at step S73 of Fig. 35, basic IVO variation
VTCNOW is calculated based on the signals from crank angle
sensor 14 and intake-valve cam angle sensor 16. At step S74,
intake valve clearance VCLI is calculated in accordance with

10 the flow chart of Fig. 31 discussed previously.

At step S75, intake-valve-temperature dependent IVO
variation correction value VTCLI is based on intake valve
clearance VCLI from a predetermined VCLI-VTCLI lookup table
of Fig. 36B showing how an intake-valve-temperature

15 dependent IVO variation correction value VTCLI has to be
varied relative to an intake valve clearance VCLI. More
concretely, in the lookup table of Fig. 36B, the vertical
broken line indicates a reference intake valve clearance
line at the steady state, the axis of abscissa of Fig. 36B

20 indicates intake valve clearance VCLI, and the axis of
ordinate of Fig. 36B indicates an intake-valve-temperature
dependent IVO variation correction value VTCLI, that is, a
deviation from an intake valve closure timing IVO
corresponding to the steady-state reference intake valve

25 clearance. As can be seen from the VCLI-VTCLI lookup table
of Fig. 36B, when intake valve clearance VCLI of intake
valve 5 decreases owing to a rise in an intake valve
temperature VTMPI (see the left-hand characteristic curve of
the steady-state reference intake valve clearance line), the

30 actual intake valve closure timing tends to phase-advance by
a phase angle corresponding to intake-valve-temperature
dependent IVO variation correction value VTCLI. The phase
advance of the actual IVO means an increase in the valve

overlap, and thus the intake-valve-temperature dependent IVO variation is increasingly compensated for based on a minus deviation of intake valve clearance VCLI from the steady-state reference intake valve clearance, in accordance with

5   the characteristic curve of Fig. 36B. Conversely when intake valve clearance VCLI increases owing to a drop in intake valve temperature VTMPI (see the right-hand characteristic curve of the steady-state reference intake valve clearance line), the actual intake valve open timing

10 tends to phase-retard by a phase angle corresponding to intake-valve-temperature dependent IVO variation correction value VTCLI. The phase retard of the actual IVO means a decrease in the valve overlap, and thus the intake-valve-temperature dependent IVO variation is decreasingly

15 compensated for based on a plus deviation of intake valve clearance VCLI from the steady-state reference intake valve clearance, in accordance with the characteristic curve of Fig. 36B.

        At step S76 of Fig. 35, IVO variation learned value
20 VTHOSI is calculated in accordance with the flow chart of Fig. 32. Then, at step S77, IVO variation VTIOFS is calculated based on (i) basic IVO variation VTCNOW, (ii) intake-valve-temperature dependent IVO variation correction value VTCLI, which is calculated or retrieved based on a

25 change in intake valve clearance VCLI, arising from a change in intake valve temperature VTMPI, and (iii) IVO-correction learned value VTHOSI, which is calculated based on a learned value for a change in intake valve clearance VCLI, arising from valve-train component-parts wear such as intake cam

30 wear and shim wear, from the following expression (24).

        VTIOFS = VTCNOW + VTCLI + VTHOSI $\cdots\cdots$(24)

        Referring now to Figs. 39 and 40, there are shown the relationship between the direction of a variation of exhaust

valve closure timing EVC and the sign of EVC variation
VTEOFS based on basic EVC variation VTCNOWE, exhaust-valve-
temperature dependent EVC variation correction value VTCLE,
and EVC-correction learned value VTHOSE, and the

5   relationship between the direction of a variation of intake
valve open timing IVO and the sign of IVO variation VTIOFS
based on basic IVO variation VTCNOW, intake-valve-
temperature dependent IVO variation correction value VTCLI,
and IVO-correction learned value VTHOSI.   As can be seen

10 from the diagrams of Figs. 39 and 40, the positive sign of
EVC variation VTEOFS is defined as a valve overlap (O/L)
increase direction, that is, an EVC retard direction (a
clockwise direction in Fig. 39), whereas the positive sign
of IVO variation VTIOFS is defined as an O/L increase

15 direction, that is, an IVO advance direction (an anti-
clockwise direction in Fig. 40).

As will be appreciated from the above, the internal EGR
amount estimation system of the embodiment described
previously, includes the EVC in-cylinder temperature

20 calculation section (serving as an EVC in-cylinder
temperature calculation means) that calculates EVC in-
cylinder temperature TEVC (see step S10), the EVC in-
cylinder pressure calculation section (serving as an EVC in-
cylinder pressure calculation means) that calculates EVC in-

25 cylinder pressure PEVC (see step S11), the exhaust-gas gas
constant calculation section (serving as an exhaust-gas gas
constant calculation means) that calculates exhaust-gas gas
constant REX (see step S9) based on target combustion
equivalent ratio TFBYA, the EVC in-cylinder residual gas

30 amount calculation section (serving as an EVC in-cylinder
residual gas amount calculation means) that calculates EVC
in-cylinder residual gas amount MRESCYL (see step S12) based
on at least the EVC in-cylinder temperature TEVC, EVC in-

cylinder pressure PEVC, and exhaust-gas gas constant REX, and the O/L period blow-back gas amount calculation section (serving as an O/L period blow-back gas amount calculation means) that calculates O/L period blow-back gas amount

5 MRESOL (see step S25) based on (i) temporary O/L period blow-back gas amount MRESOLtmp properly calculated depending on both of supercharging-phenomenon decision flag TBCRG and choking-phenomenon decision flag CHOKE and (ii) O/L period integrated effective area ASUMOL. The internal EGR amount

10 per cylinder MRES (unit: kg) is arithmetically calculated by adding O/L period blow-back gas amount MRESOL to EVC in-cylinder residual gas amount MRESCYL (see step S7). Therefore, internal EGR amount per cylinder MRES can be calculated or estimated from the previously-noted physical

15 expression (3), on the basis of quantities of state of the inside of the cylinder after combustion has been completed, that is, EVC in-cylinder temperature TEVC, EVC in-cylinder pressure PEVC, and exhaust-gas gas constant REX. Additionally, according to the system of the embodiment,

20 internal EGR amount per cylinder MRES can be more precisely estimated regardless of the engine operating conditions, since internal EGR amount per cylinder MRES is suitably compensated for responsively to a change in the density of gas, flowing between intake and exhaust ports 5p and 6p via

25 combustion chamber 3 during a valve overlap period, the gas flow being created by the pressure difference between the pressure in the intake port and the pressure in the exhaust port. The change in gas density occurs owing to a temperature TEVC change and a pressure PEVC change of the

30 gas flowing between intake and exhaust ports 5p and 6p via combustion chamber 3 during a valve overlap period, and/or owing to a change in exhaust-gas gas constant REX that varies due to a change in the air-fuel mixture ratio (that

is, a change in the combustion equivalent ratio (see the
lookup table of Fig. 18). Even in a transient state where
quantities of state of the inside of the cylinder are
continuously changing, internal EGR amount per cylinder MRES

5   can be suitably compensated for and accurately estimated
responsively to a change in each of the quantities of state
of the inside of the cylinder during the valve overlapping
period. This greatly enhances the accuracy of estimation of
internal EGR amount per cylinder MRES in transient engine

10   operating conditions. By virtue of such very precise
estimation of internal EGR amount per cylinder MRES, it is
possible to suitably control the ignition timing, the fuel
injection amount, the IVO, IVC, EVO, and EVC (in particular,
the valve overlapping period from the beginning-of-valve-

15   overlap crank angle, i.e., IVO to the end-of-valve-overlap
crank angle, i.e., EVC), during operation of the engine. As
may be appreciated from the above, it will be understood
that the sort of parameters and the number of parameters
needed to calculate or estimate internal EGR amount per

20   cylinder MRES are not limited to the particular embodiment
shown and described herein. For instance, even in a higher-
order control structure further including an additional
parameter, internal EGR amount per cylinder MRES can be more
precisely calculated fundamentally from the previously-

25   discussed physical expression (3), and thereafter the
controlled variable for each parameter is determined based
on the internal EGR amount per cylinder MRES calculated, so
as to more precisely control the ignition timing, the A/F
mixture ratio, and the valve overlapping period.

30   Additionally, the internal EGR amount estimation system
of the embodiment described previously, further includes the
EVC in-cylinder volumetric capacity calculation section
(serving as an EVC in-cylinder volumetric capacity

calculation means) that calculates EVC in-cylinder volumetric capacity VEVC (see step S8). EVC in-cylinder residual gas amount MRESCYL (unit: kg) can be arithmetically calculated based on the calculated values VEVC, REX, TEVC,

5 and PEVC, from the physical expression (4). Therefore, internal EGR amount per cylinder MRES can be calculated or estimated from the previously-noted physical expression (3), on the basis of quantities of state of the inside of the cylinder after combustion has been completed, that is, EVC

10 in-cylinder volumetric capacity VEVC, EVC in-cylinder temperature TEVC, EVC in-cylinder pressure PEVC, and exhaust-gas gas constant REX. In this case, internal EGR amount per cylinder MRES can be more precisely estimated regardless of the engine operating conditions, since

15 internal EGR amount per cylinder MRES is suitably compensated for responsively to a gas-density change of the gas flow between intake and exhaust ports 5p and 6p via combustion chamber 3 during a valve overlap period, occurring due to a temperature TEVC change, a pressure PEVC

20 change, and/or a change in exhaust-gas gas constant REX.

Additionally, in the system of the embodiment, the EVC in-cylinder volumetric capacity calculation section geometrically determines EVC in-cylinder volumetric capacity VEVC based on the position of reciprocating piston 2 at the

25 exhaust valve closure timing EVC (see step S8). Therefore, EVC in-cylinder volumetric capacity VEVC can be more precisely calculated, thereby ensuring more precise estimation of internal EGR amount per cylinder MRES. Additionally, on internal combustion engines also employing

30 a variable compression ratio mechanism (a variable piston stroke characteristic mechanism) enabling a compression ratio ε of the engine to be continuously varied, EVC in-cylinder volumetric capacity VEVC may be easily, accurately,

and geometrically calculated based on a variation $\Delta\varepsilon$ of compression ratio ε controlled by means of the variable compression ratio mechanism. Geometrically calculating and determining EVC in-cylinder volumetric capacity VEVC ensures

5 more precise estimation of internal EGR amount per cylinder MRES, and also facilitates a more effective engineering design development for the internal EGR estimation system.

Additionally, in the system of the embodiment, the exhaust-gas gas constant calculation section (serving as an

10 exhaust-gas gas constant calculation means) calculates exhaust-gas gas constant REX (see step S9) based on target combustion equivalent ratio TFBYA, in such a manner that exhaust-gas gas constant REX matches a change in a composition of exhaust gas (see the predetermined TFBYA-REX

15 lookup table of Fig. 18). Therefore, even in case of a change in gas density, arising from a change in the exhaust-gas composition that depends on target combustion equivalent ratio TFBYA, that is, even in the presence of a remarkable increase or decrease in target combustion equivalent ratio

20 TFBYA, for example, during a lean A/F mixture combustion mode, during after-start enrichment, after switching to the full throttle operating mode, it is possible to very precisely estimate internal EGR amount per cylinder MRES. Also, exhaust-gas gas constant REX can be easily calculated

25 or estimated from a reaction formula for a composition of fuel and a composition of intake air (fresh air). Estimating or calculating exhaust-gas gas constant REX from the reaction formula for a composition of fuel and a composition of air facilitates a more effective engineering design

30 development for the internal EGR estimation system.

In addition to the above, in the system of the embodiment, the temporary O/L period blow-back gas amount MRESOLtmp calculation section (see step S25) includes the EVC

in-cylinder temperature calculation section (serving as an
EVC in-cylinder temperature calculation means) that
calculates EVC in-cylinder temperature TEVC (see step S10),
the EVC in-cylinder pressure calculation section (serving as

5   an EVC in-cylinder pressure calculation means) that
calculates EVC in-cylinder pressure PEVC (see step S11), the
exhaust-gas gas constant calculation section (serving as an
exhaust-gas gas constant calculation means) that calculates
exhaust-gas gas constant REX (see step S9) based on target

10   combustion equivalent ratio TFBYA, the intake pressure
calculation section (serving as an intake pressure
calculation means) that calculates or estimates intake
pressure PIN (detected by intake pressure sensor 10 in the
shown embodiment), the gas ratio-of-specific-heat

15   calculation section (serving as a gas ratio-of-specific-heat
calculation means) that calculates exhaust-gas ratio-of-
specific-heat SHEATR corresponding to a change in a
composition of exhaust gas (see step S16) and calculates
air-fuel mixture ratio-of-specific-heat MIXAIRSHR

20   corresponding to a change in a composition of air-fuel
mixture (see step S30), the O/L period integrated effective
area calculation section (serving as an O/L period
integrated effective area calculation means) that calculates
O/L period integrated effective area ASUMOL based on the

25   valve overlap (in the system of the embodiment, O/L period
integrated effective area ASUMOL is based on the variation
VTCOL of valve overlap O/L during the valve overlapping
period (see step S14), in other words, O/L period integrated
effective area ASUMOL is based on EVC variation VTEOFS and

30   IVO variation VTIOFS (see Fig. 27)), the engine speed
calculation section (serving as an engine speed calculation
means) that calculates engine speed NRPM (see step S15), and
the supercharging-and-choking phenomena determination

section (serving as a supercharging-and-choking phenomena
determination means) that determines the presence (TBCRG=1)
or absence (TBCRG=0) of the supercharging phenomenon and
additionally determines the presence (CHOKE=1) or absence
5   (CHOKE=0) of the choking phenomenon regarding gas flow
between intake and exhaust ports 5p and 6p via combustion
chamber 3 during a valve overlap period, created by the
pressure difference between the pressure in the intake port
and the pressure in the exhaust port (see steps S17, S27,
10   and S32). O/L period blow-back gas amount MRESOL (unit: kg)
can be arithmetically calculated based on these calculated
values TEVC, PEVC, REX, PIN, SHEATR, ASUMOL, and NRPM, and
the supercharging-phenomenon decision result (TBCRG=0 or
TBCRG=1) and the choking-phenomenon decision result (CHOKE=0
15   or CHOKE=1), from the physical expression (6). Therefore,
it is possible to very precisely estimate O/L period blow-
back gas amount MRESOL based on quantities of state of the
valve overlap period, that is, EVC in-cylinder temperature
TEVC, EVC in-cylinder pressure PEVC, exhaust-gas gas
20   constant REX, exhaust-gas ratio-of-specific-heat SHEATR,
engine speed NRPM, and O/L period integrated effective area
ASUMOL, and the presence (TBCRG=1) or absence (TBCRG=0) of
the supercharging phenomenon, and the presence (CHOKE=1) or
absence (CHOKE=0) of the choking phenomenon, from the
25   physical expression (6). As a result, responsively to a
change in each state quantity, that is, a gas-density change
and a volumetric-flow-rate change in gas passing through the
previously-discussed pseudo variable orifice defined by the
intake and exhaust ports both opening, it is possible to
30   more precisely calculate or estimate O/L period blow-back
gas amount MRESOL through all engine operating conditions.

Additionally, in the system of the embodiment, the
supercharging-and-choking phenomena determination section

(serving as a supercharging-and-choking phenomena
determination means) further includes the intake-pressure-
to-exhaust-pressure ratio calculation section (serving as an
intake-pressure-to-exhaust-pressure ratio calculation means)
5   that calculates pressure ratio PINBYEX of intake pressure to
exhaust pressure based on both the intake pressure PIN and
EVC in-cylinder pressure PEVC, from the expression (7).
When the supercharging phenomena determination section
(serving as a supercharging phenomena determination means
10   and relating to step S27) determines, based on the
predetermined condition (PINBYEX≤1), that the supercharging
phenomenon is absent (TBCRG=0) during the valve overlap
period, exhaust-gas ratio-of-specific-heat SHEATR retrieved
from the predetermined TFBYA-SHEATR characteristic map of
15   Fig. 21, is used to calculate or estimate temporary O/L
period blow-back gas amount MRESOLtmp (O/L period blow-back
gas amount MRESOL). Conversely when the supercharging
phenomena determination section (serving as a supercharging
phenomena determination means and relating to step S27)
20   determines, based on the predetermined condition (PINBYEX>1),
that the supercharging phenomenon is present (TBCRG=1)
during the valve overlap period, exhaust-gas ratio-of-
specific-heat SHEATR retrieved from the predetermined TFBYA-
SHEATR characteristic map of Fig. 21, is replaced with air-
25   fuel mixture ratio-of-specific-heat MIXAIRSHR retrieved from
the predetermined TFBYA-MIXAIRSHR characteristic map of Fig.
22. In this manner, the ratio of specific heat can be
suitably set depending on a composition of gas flowing
between the intake and exhaust ports via the combustion
30   chamber during the valve overlap period. Therefore, even in
the presence of the supercharging phenomenon, for example in
the supercharged state on turbocharged engines or
supercharged engines or during inertia supercharging at

full-throttle operation, it is possible to very precisely estimate O/L period blow-back gas amount MRESOL. Additionally, even in the presence (CHOKE=1) of the choking phenomenon, for example during engine idling, it is possible

5   to very precisely estimate O/L period blow-back gas amount MRESOL.

Additionally, the system of the embodiment includes the valve-overlap variation calculation section (serving as a valve-overlap variation calculation means) that calculates

10   the variation VTCOL of valve overlap O/L based on (i) the variation VTIOFS of intake valve open timing IVO and (ii) the variation VTEOFS of exhaust valve closure timing EVC (see step S13), and the O/L period integrated effective area calculation section (serving as an O/L period integrated

15   effective area calculation means) that calculates O/L period integrated effective area ASUMOL based on the valve-overlap variation VTCOL (see step S14 and Figs. 19 and 20). Therefore, O/L period integrated effective area ASUMOL can be easily accurately estimated based on the valve overlap

20   that is determined based on the valve-overlap variation VTCOL and can also be regarded as a pseudo variable orifice (a variable flow-constriction orifice) that serves to variably constrict the gas flow between intake and exhaust ports 5p and 6p via combustion chamber 3. As discussed

25   previously, by way of the aforementioned select-LOW process and the integral of an effective opening area per unit crank angle (or unit time) from a time point (IVO) corresponding to the beginning-of-valve-overlap crank angle to a time point (EVC) corresponding to the end-of-valve-overlap crank

30   angle, O/L period integrated effective area ASUMOL can be arithmetically calculated. In this case, O/L period integrated effective area ASUMOL can be regarded as an orifice size of the pseudo variable orifice. Thus, it is

possible to simply calculate or estimate the flow rate of gas passing through the pseudo variable orifice, defined between the intake and exhaust ports. In lieu thereof, when O/L period integrated effective area ASUMOL is more simply

5 map-retrieved based on the valve-overlap variation VTCOL from the predetermined VTCOL-ASUMOL characteristic map as shown in Fig. 19. Such map-retrieval for O/L period integrated effective area ASUMOL (see Fig. 19) is superior to arithmetic calculation containing the select-LOW process

10 and the integral of an effective opening area per unit crank angle (or unit time) from IVO to EVC, from the viewpoint of the reduced load on the computer.

Furthermore, the internal EGR amount estimation system of the shown embodiment includes a variable intake-valve

15 timing mechanism, which is comprised of an electromagnetic intake-valve solenoid 22 enabling at least an intake valve open timing IVO of intake valve 5 to be varied, and a variable exhaust-valve timing mechanism, which is comprised of an electromagnetic exhaust-valve solenoid 23 enabling at

20 least an exhaust valve closure timing EVC of exhaust valve 6 to be varied, and a valve timing calculation section (serving as a valve timing calculation means) that estimates or calculates at least (i) an intake valve open timing IVO based on an IVO variation VTIOFS adjusted by the variable

25 intake-valve timing mechanism and affected by the valve temperature change and the cam and shim wear and (ii) an exhaust valve closure timing EVC based on an EVC variation VTEOFS adjusted by the variable exhaust-valve timing mechanism and affected by the valve temperature change and

30 the cam and shim wear. The valve timing calculation section includes a valve clearance estimation section (serving as a valve clearance estimation means) that estimates a valve clearance VCLE (VCLI), taking into account a variation of

valve clearance, occurring owing to thermal expansion of the
engine valve and motion-transmitting valve-train component
parts wear (see step S48 of Fig. 30 and step S74 of Fig. 35),
and a valve timing compensation section (serving as a valve

5   timing compensation means) that compensates for exhaust
valve closure timing EVC based on exhaust valve clearance
VCLE estimated and compensates for intake valve open timing
IVO based on intake valve clearance VCLI estimated (see
steps S49 and S50 of Fig. 30 and steps S75 and S76 of Fig.

10   35). Therefore, valve timings EVC and IVO are properly
compensated for based on the respective valve clearances
VCLE and VCLI estimated, thus reducing the error of
estimation of the valve overlap, that is, the error of
estimation of internal EGR amount MRES to a minimum and

15   enhancing the accuracy of estimation of internal EGR amount
MRES. By virtue of more precisely estimated internal EGR
amount MRES, it is possible to more suitably set the
ignition timing, the fuel injection amount, and the like,
thereby enhancing the vehicle drivability, improving fuel

20   economy, and reducing exhaust emissions.

        Additionally, in the system of the embodiment, the
valve clearance estimation section (see step S48 of Fig. 30
and step S74 of Fig. 35) includes the valve temperature
calculation section (serving as a valve temperature

25   calculation means) that calculates or estimates exhaust
valve temperature VTMPE and intake valve temperature VTMPI
(see step S52 of Fig. 31) so as to estimate exhaust valve
clearance VCLE and intake valve clearance VCLI based on the
respective valve temperatures VTMPE and VTMPI (see steps

30   S53-S56). In this manner, intake and exhaust valve
clearances VCLI and VCLE can be estimated based on the
respective valve temperatures VTMPI and VTMPE each acting as
a principal factor that has a great influence on variations

in valve clearance. Therefore, even when the engine
operating condition is changing from starting with a cold
engine to high load operation, and thus there is a
remarkable valve-temperature change for each of intake and
5   exhaust valves 5 and 6, it is possible to accurately
estimate intake and exhaust valve clearances VCLI and VCLE,
and consequently to reduce the error of estimation of
internal EGR amount MRES, which error may arise from the
valve-clearance change occurring owing to the valve-
10   temperature change, to a minimum.

     According to the system of the embodiment, the valve
temperature calculation section (see step S52) includes an
engine load calculation section (serving as an engine load
calculation means) that estimates or calculates the engine
15   load (correlated to the fuel injection amount) based on the
intake-air quantity per cylinder (the fresh-air quantity per
cylinder) MACYL computed based on the intake-air quantity
measured by airflow meter 9. That is, exhaust valve
temperature VTMPE and intake valve temperature VTMPI can be
20   estimated or calculated depending on the engine load, i.e.,
the fuel injection amount (see the lookup tables of Figs.
37A and 37B). This eliminates the necessity of temperature
sensors that directly sense the respective valve
temperatures VTMPE and VTMPI, thereby reducing manufacturing
25   costs.

     In the shown embodiment, (i) an exhaust valve clearance
estimation section (see step S48 of Fig. 30) plus exhaust
valve timing compensation section, exactly, EVC compensation
section (see steps S49 and S50 of Fig. 30) for the exhaust
30   valve side, and (ii) an intake valve clearance estimation
section (see step S74 of Fig. 35) plus intake valve timing
compensation section, exactly, IVO compensation section (see
steps S75 and S76 of Fig. 35) for the intake valve side, are

provided independently of each other. As is well known, exhaust valve clearance VCLE tends to differ from intake valve clearance VCLI owing to various factors, such as an intake valve temperature range different from an exhaust

5 valve temperature range, a material forming intake valve 5 different from a material forming exhaust valve 6, a shape of intake valve 5 different from a shape of exhaust valve 6, and the like. Even in such a case that intake and exhaust valve clearances VCLI and VCLE differ from each other, IVO

10 variation VTIOFS and EVC variation VTEOFS can be accurately calculated or estimated independently of each other. This insures very precise estimation of internal EGR amount MRES. Also, even in case of an intake cam-profile design peculiar to an intake valve operating system and an exhaust cam-

15 profile design thus different from the intake cam-profile design, by way of the individual valve timing variation calculation routines of Figs. 30 and 35, EVC variation VTEOFS and IVO variation VTIOFS can be accurately calculated independently of each other, taking into account exhaust-

20 valve-temperature dependent EVC variation correction value VTCLE and intake-valve-temperature dependent IVO variation correction value VTCLI. This insures very precise estimation of EVC and IVO, and consequently insures very precise estimation of internal EGR amount MRES.

25 Moreover, in the system of the embodiment, the valve timing compensation section (see steps S49 and S50 of Fig. 30 and steps S75 and S76 of Fig. 35) includes a valve-timing real value calculation section (serving as a valve timing real value calculation means) that calculates or detects EVC

30 real value VCLTRE and IVO real value VCLTRI based on at least the frequency of oscillatory seating motion of each of exhaust valve 6 and intake valve 5 (see step S59) under a predetermined condition (see steps S64-S67) that the engine

is conditioned in the valve timing detectable engine
operating state suited to precisely detect or extract EVC
real value VCLTRE and IVO real value VCLTRI, a valve-timing
estimate calculation section or a valve timing estimation

5   section (serving as a valve timing estimation means) that
calculates, under the predetermined condition (see steps
S64-S67), EVC estimate VCLTEE and IVO estimate VCLTEI of the
exhaust valve closure timing and the intake valve open
timing already compensated for based on exhaust and intake

10   valve clearances VCLE and VCLI both temperature-compensated
for in full consideration of changes in exhaust and intake
valve temperatures VTMPE and VTMPI (see step S60 of Fig. 32),
a valve timing error calculation section (serving as a valve
timing error calculation means) that calculates a difference

15   between the valve-timing real value and the valve-timing
estimate (exactly, an exhaust valve timing error
(VTHOSEtmp=VCLTRE-VCLTEE) between EVC real value VCLTRE and
EVC estimate VCLTEE and an intake valve timing error
(VTHOSItmp=VCLTRI-VCLTEI) between IVO real value VCLTRI and

20   IVO estimate VCLTEI) (see step S61 of Fig. 32), and a wear
dependent valve-timing-correction learned value calculation
section (serving as a wear-dependent valve-timing-correction
learned value calculation means) that calculates EVC-
correction learned value VTHOSE based on exhaust valve

25   timing error (VTHOSEtmp=VCLTRE-VCLTEE) and calculates IVO-
correction learned value VTHOSI based on intake valve timing
error (VTHOSItmp=VCLTRI-VCLTEI) (see step S63 of Fig. 32).
Exhaust valve closure timing EVC and intake valve open
timing IVO, exactly, EVC variation VTEOFS and IVO variation

30   VTIOFS can be more accurately compensated for, taking into
account EVC-correction learned value VTHOSE and IVO-
correction learned value VTHOSI, in addition to exhaust-
valve-temperature dependent EVC variation correction value

VTCLE and intake-valve-temperature dependent IVO variation correction value VTCLI. As discussed above, according to the system of the embodiment, it is possible to more precisely detect EVC real value VCLTRE and IVO real value

5 VCLTRI in the predetermined engine operating range wherein the frequency of oscillatory seating motion of each of exhaust valve 6 and intake valve 5 can be more accurately detected, for example, in a low engine speed range that valve seating noise can be accurately detected, in a low

10 engine load range that there is less possibility of knocking, or in a less valve-timing-error operating range that a basic valve-timing variation (basic EVC variation VTCNOWE and basic IVO variation VTCNOW) is "0" and the engine has already been warmed up. The previously-noted valve timing

15 errors, namely exhaust valve timing error ($VTHOSE_{tmp}=VCLTRE-VCLTEE$) and intake valve timing error ($VTHOSI_{tmp}=VCLTRI-VCLTEI$) are caused by valve-train component-parts wear. Such valve timing errors ($VTHOSE_{tmp}=VCLTRE-VCLTEE$) and ($VTHOSI_{tmp}=VCLTRI-VCLTEI$), caused by such wear, constantly

20 and continually exert an influence on the respective valve timings, that is, EVC and IVO, through all engine operating conditions. According to the system of the embodiment, it is possible to compensate for the valve timings, namely EVC and IVO, in advance by the wear-dependent valve timing

25 errors ($VTHOSE_{tmp}=VCLTRE-VCLTEE$) and ($VTHOSI_{tmp}=VCLTRI-VCLTEI$), arising from valve-train component-parts deteriorated with age.

Additionally, in the system of the embodiment, the frequency of oscillatory seating motion of each of intake

30 and exhaust valves 5 and 6 is detected based on a signal from knock sensor 25. Thus, it is possible to detect the frequency of oscillatory seating motion of each engine valve based on input information from the existing knock sensor

usually installed on an internal combustion engine. This reduces manufacturing costs of internal EGR amount estimation systems of internal combustion engines.

In the shown embodiment, the variable intake-valve
5   timing mechanism enabling intake valve open timing IVO to be varied and the variable exhaust-valve timing mechanism enabling exhaust valve closure timing EVC to be varied are both provided. The fundamental concept of the internal EGR amount estimation system of the embodiment is not limited to
10   an internal combustion engine having both of the variable intake-valve timing mechanism and the variable exhaust-valve timing mechanism. Actually, it is possible to change a valve overlap, and thus to change internal EGR amount MRES, by varying at least one of valve lift characteristics of
15   intake and exhaust valves 5 and 6 (exactly, intake valve open timing IVO and exhaust valve closure timing EVC). As appreciated from the above, the system of the embodiment may be applied to an internal combustion engine having at least one of the variable intake-valve timing mechanism and the
20   variable exhaust-valve timing mechanism.

The entire contents of Japanese Patent Application Nos. 2002-272670 (filed September 19, 2002) and 2003-016828 (filed January 27, 2003) are incorporated herein by reference.

25   While the foregoing is a description of the preferred embodiments carried out the invention, it will be understood that the invention is not limited to the particular embodiments shown and described herein, but that various changes and modifications may be made without departing from
30   the scope or spirit of this invention as defined by the following claims.